GEOLOGY OF THE CHESAW AREA, OKANOGAN COUNTY, WASHINGTON

By

THURSTON MASON PHETTEPLACE

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Approved by Peter Misch
Department Geology
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GEOLOGY OF THE CHESAW AREA, OKANOGAN COUNTY, WASHINGTON

INTRODUCTION

Location and Accessibility

The area is situated about twenty miles east of Oroville in Okanogan County, Washington (Figure 1). It lies between the valleys of Myers Creek on the east and of the north-south segment of Mary Ann Creek to the west. It is bounded on the north by the International line, while at the southern apex lies the village of Chesaw, the only settlement in the vicinity. This area comprises roughly fifteen square miles. It may be reached most easily by a good secondary road from Oroville, or from the Tonasket-Republic highway to the south and Toroda Creek valley to the east by minor roads.

Topography and Culture

The topography consists of gently rolling upland and steep bluffs facing the valley of Myers Creek. The landscape has been vastly modified by glaciation. The uplands as well as the valleys are largely mantled by a fine black soil which nourishes a luxuriant growth of grass or grain. Only a few of the highest elevations are forested. Exposures are common along the ridges and the bluffs overlooking Myers Creek valley, but

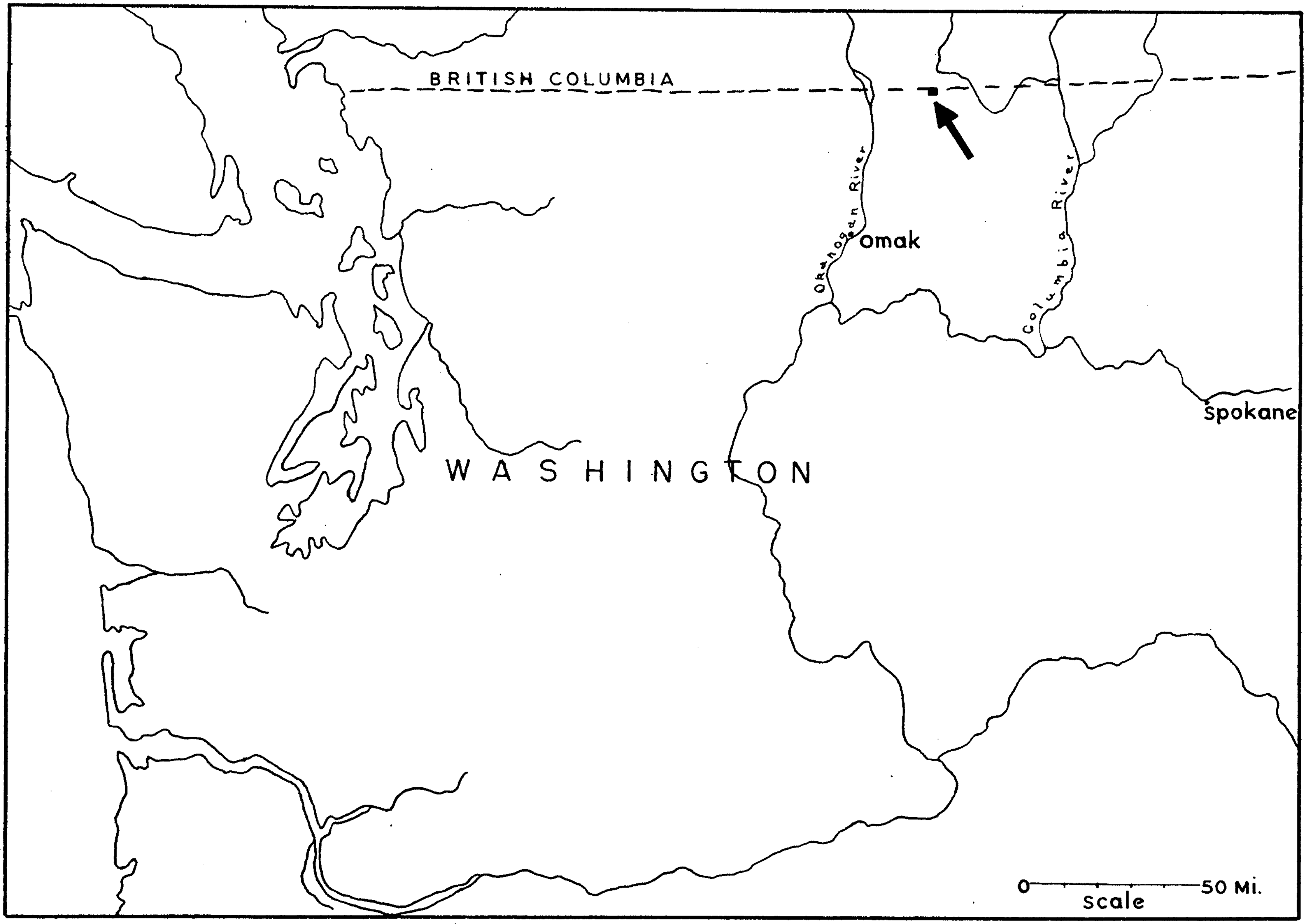


Fig. 1. INDEX MAP SHOWING LOCATION OF THESIS AREA

infrequent on the lower slopes to the west and south and in a large shallow basin in the central part of the area. The maximum relief in the area is about 1700 feet, from an elevation of 2700 feet in lower Myers Creek valley to an elevation of 4400 feet at Bolster Peak.

The principal occupations are the raising of cattle and wheat, although the season is so short that frequently the wheat fails to mature before the fall rains set in, and the harvest is lost. Some logging is done, and small saw mills are located at convenient points.

MINING

This area, together with Buckhorn Mountain, which forms the eastern side of Myers Creek valley, and the valleys of Mary Ann Creek and its tributaries, has been designated the Myers Creek Mining District by Umpleby (8). He described some of the numerous prospects which dot the area. Most of the workings are now caved in, so that their original extent can only be guessed at. Judging from the size of the dumps, none of them appears to be very extensive, and, in fact, according to Umpleby (cf. above), the maximum length of the adits is only a few hundred feet. Material on the dumps was largely pyritic, but in one or two instances galena was noted in small amounts, while malachite stains were occasionally observed. The adits and shafts in most cases were driven either into outcrops of the acidic intrusives, or into contacts between them and the country rock, often where the appearance of wide bull quartz veins apparently offered added inducement.

Evidently, considerably more was expended on development than was ever realized from ore removed, as Umpleby (8) sets the total production at probably under $100,000, of which about 40% came from placers. Most of the workings have long since been abandoned, and, during the field season of 1951, the only prospect being worked was the Gray Eagle Claim, about one mile north of Chesaw along the road (Plate 1), where two partners were engaged in hand tool exploitation of a silicified and carbonatized rock in a small shear zone next to a body of tonalite. Considerable pyrite was visible with a hand lens. A thin section revealed scattered euhedra, and a band or veinlet of finely divided pyrite in a matrix of coarse-grained brecciated quartz and sericite. No free gold or other sulfides could be detected.

The most promising mineral deposit in the region is situated high on the west flank of Buckhorn Mountain. It is a contact metamorphic deposit, formed at the margin of a limestone pod, where it was invaded by a body of syenite (8). The principal ore mineral is magnetite, with a garnet-epidote gangue. The deposit has been worked spasmodically on a small scale.

PREVIOUS WORK

In 1909 a rapid field reconnaissance of the area was made by Umpleby, and the report was published as a bulletin of the Washington State Geological Survey. He separated the Paleozoic rocks into two groups: (1) quartzites, schists and greenstones; and (2) limestones, crushed and metamorphosed. These he found intruded by a granite of doubtful Mesozoic age.

Daly, in his "Geology of the North American Cordillera at the Forty-ninth Parallel," described these rocks and proposed the name "Anarchist" for them, because of the confusion of their structural relationships. He tentatively assigned them to the Carboniferous.

Subsequent work has been done on the western margin of this area by

Plate 1. View of Grey Eagle property one mile north of Chesaw as it looked in October, 1951, showing small diggings with ore chute running to hand-made mill.

Waters and Krauskopf. In their "Protoclastic Borders of the Colville Batholith," they subdivided the Anarchist series into Lower, Middle and Upper, the Lower consisting predominantly of phyllites, the Middle of quartzites, metaconglomerates, limestones, and some metavolcanics, and the Upper of andesites and basalts metamorphosed commonly into massive greenstones and locally into chloritic and amphibolitic schists. They assigned the series as a whole to late Paleozoic time, probably Permian, on the basis of a few poor collections of gastropods, brachiopods and pelecypods.

BACKGROUND FOR THESIS

Field work was accomplished during the course of 47 days in the field seasons of 1950 and 1951. Some 450 samples were collected. From these, 195 thin sections were prepared and examined. Due to the infinite number of gradations in lithology, it was felt that only a very intensive petrographic study would be of any value in determining probable genesis and lithologic relationships. More thin sections would, no doubt, add further light, but it is believed that the number examined was sufficient to delineate the major rock types and to indicate their probable derivations.

The geologic map was prepared from aerial photographs taken by the Soil Conservation Service of the Department of Agriçulture. The scale of 1000 feet to the inch is that of the photographs, but it was checked for accuracy against known distances in the field. The "north line" was taken from the "flight line" in the "master" photograph, but it, too, was substantiated from authenticated fence lines.

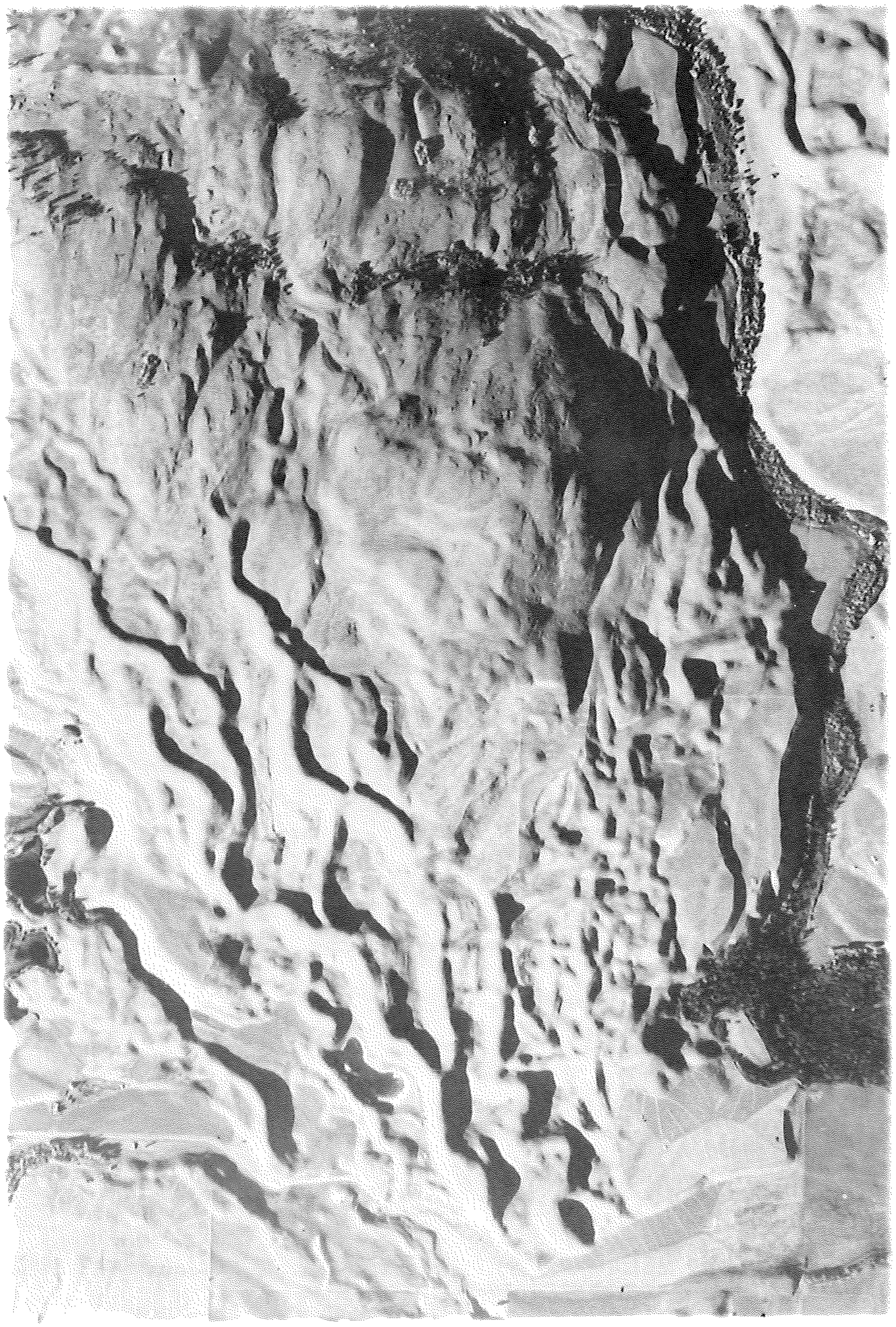
GLACIATION

The various effects of glaciation are everywhere present in the area. The uplands are dotted with erratics, as much as six feet across. The majority are granitic, but greenstone or even limestone boulders are not unusual. In spite of the number of erratics, there is apparently little till covering the upland areas. Soil cover is thin, as indicated by the frequency of planed-off outcrops. Striae are common and have an over-all southeasterly trend. The soil is mouse-colored, powdery, and is believed to be of loessic origin.

Terraces are present at several levels along both sides of Myers Creek valley, and along Mary Ann Creek and its tributary valleys to the west. Frequently, associated with the terraces, are shallow troughs, sometimes in series, oriented parallel to the valley. They are cut into rock and floored with a thin mantle of drift. Some of these troughs persist for a considerable distance; others apparently represent notches cut through spurs that protruded into the ice. They are believed to be ice-marginal channels, minor examples of similar features described by Flint in the lower Okanogan and Columbia valleys (4). In many instances, these ice-marginal channels are apparently combined with or superimposed on terraces. Most of the higher terraces are fills, probably formed by ice-marginal streams. Some, especially in lower Myers Creek valley, and on the east side upstream from Chesaw, are probably stream cut, as outcrops can be seen in some places not far below the present surface. Occasional rugged erosional remnants of greenstone protrude above the valley floor. All of these terraces are mantled by the same fine soil that covers the uplands.

The lower slopes to the southwest are marked by numerous kames, eskers, and kettles, and, usually at somewhat higher levels, by sinuous channels. These have smoothly rounded floors, are usually from twenty to thirty feet deep and about the same in width. They seem to have a roughly radial pattern, extending like fingers into the valley from the higher elevations. The eskers form crude networks trending roughly south 10-20 east (Plate 2). These are concentrated along both sides of Mary Ann Creek in the extreme southwestern corner of the area. Along with the eskers, and apparently gradational into them, are groups of kames, irregularly distributed over a rather wide area, mostly just south and west of lower Mary Ann Creek before it bends sharply to the east to flow into Myers Creek. The kames are steep-sided, composed chiefly of coarse gravel, and range from a few feet to forty feet or more in height. They were presumably formed by flowing meltwater in crevasses, hollows, and other openings in wasting ice.

Kettles, many of them currently occupied by small ponds, are found among the eskers and here and there on the upland surface as well. A huge kettle, worthy of special mention, occurs on the east side of Myers Creek valley, about two miles south of the field area. Its floor is evidently part of the lowest terrace on this side of the valley, and it marks the southernmost extent of this terrace. It is a giant bowl, open to the north, whose rim is formed by the next higher terrace. It is about three hundred feet across and one hundred feet deep. According to Flint (4), this indicates that buried ice was present while the upper terraces were being formed, as he found similar kettle-bearing terraces in the lower Okanogan and adjacent Columbia valleys.



1000 feet

Plate 2. Network of eskers and associated kames and kettles just west of Mary Ann Creek. Note general southeasterly trend. Near bottom of picture is Oroville-Chesaw road, following coulee believed to be responsible for diversion of Mary Ann Creek to the east at sharp bend seen at lower right.

(Reproduced from air photograph)

Thickness of the ice in this area is estimated at about 4500 feet by Daly (2), which would be considerably more than enough to completely submerge Buckhorn Mountain, the highest elevation in the immediate vicinity. Pronounced glacial groovings were observed in the limestone ledges high on the west flank of Buckhorn. In the Methow area, west of the Okanogan valley, Barksdale found evidence of glaciation at elevations up to 7200 feet (1).

Drainage

Drainage must have been to the south during the time of the ice advance and up to a certain point in its retreat. Not only Myers Creek valley, but Toroda Creek and the valley occupied by Curlew Creek, head up into very low divides to the south. Lakes in two of these valleys testify to the disturbed drainage. It is possible that the pre-glacial course of the Kettle River, or some larger stream, may have been through Myers Creek valley. The present valley, at least the lower end of it, is far too large to have been cut by a stream the size of Myers Creek, even allowing for some glacial excavation. Myers Creek wanders through it in a maze of meanders, many of them cut off into tiny ox-bow lakes. South of Chesaw, the gradient steepens perceptibly, and two miles further up, the stream is a rushing torrent in a narrow gorge.

The valley, then, appears to narrow rapidly to the south until it forms a mere notch, which in the saddle between Bonaparte Mountain and the ridge to the east is occupied by a chain of ponds. This narrowing may be purely illusory and due to vigorous recent down-cutting by Myers Creek, which, in this portion of the valley, has a rather steep gradient. It is quite possible that this upper end of the valley has been choked with morainal debris and outwash, deposited at the time that wasting ice on the uplands was creating the depositional forms described previously.

Aside from Myers Creek being an underfit stream where it approaches the border, there is additional evidence for the hypothesis that this valley was formerly host for the Kettle River. A glance at the drainage map (Figure 2) will show that before the Kettle River bends sharply to the east, near the Canadian village of Rock Creek, its course is directly in line with Myers Creek valley. Myers Creek itself, instead of joining the Kettle River near the confluence of the river with Rock Creek, actually swings to the east and enters the river some distance further downstream. The valley floor, however, extends without a break to the point where Rock Creek joins the Kettle River. This area is occupied by ponds and bog, remnants of a former waterway.

Stream diversion has also affected Mary Ann Creek and other minor subsequents, now tributary to Myers Creek. Their upper courses are directly in line with north-south trenches beyond the line where they now turn abruptly to the east to flow into Myers Creek. Their courses are believed to have been radically altered by channels developed during the melting of the ice. Such a channel or coulee is followed by the Chesaw-Oroville road from Chesaw to the summit of the upland four or five miles to the west. Mary Ann Creek and other small tributaries make almost a 90-degree turn to the east where they intersect this channel.

The apparent diversion of Kettle River from Myers Creek valley bears a striking resemblance to the situation of the Similkameen at Miners Bend, where, instead of following a broad valley to the south, it turns

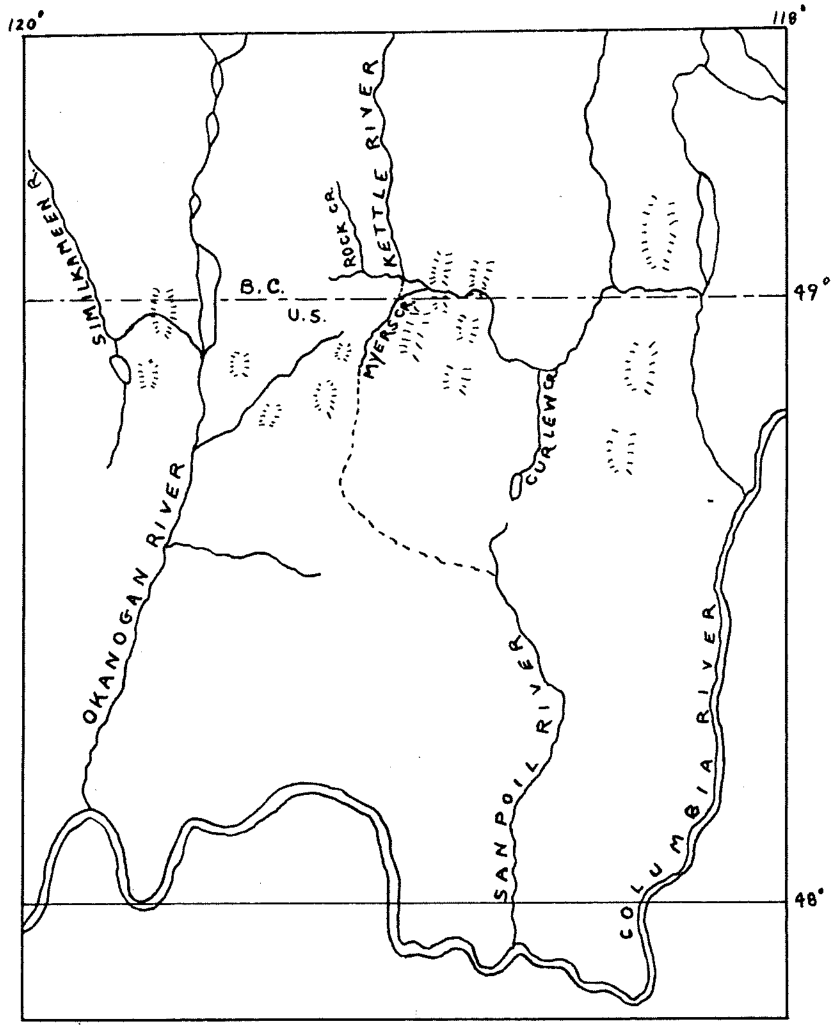


Fig. 2. Diagrammatic map* of drainage in north-eastern Washington and southeastern British Columbia showing eastward diversion of streams by glacial damming of north-south valleys.

-------- Hypothetical course of pre-glacial Kettle River.

* After R. A. Daly.

sharply east and cuts through Kruger Mountain to join the Okanogan. Willis (10) suggested that the diversion was due to clogging of the valley by a temporary terminal moraine and general damming from glacial debris accumulated during retreat of the ice. An evidently similar case exists also where the Kettle River ignores the low broad valley of Curlew Creek to flow north again before finally looping south to join the Columbia. Willis (cf. above) believed that the present valley of Curlew Creek was cut by a major stream, to which the present Kettle River, or that segment of it west of Curlew Creek valley (and, perhaps, east of Myers Creek valley), was tributary. In short, the major drainage system of this area in pre-glacial times is believed to have had a north-south orientation instead of the east-west trend of today. The general eastward direction of diversion is obviously due to the regional slope, and the east-west courses of these streams, then, may in a sense be said to be consequent upon it.

GENERAL STATEMENT

Lithology

The rocks of the area consist predominantly of metamorphosed quartzites, argillites, and limestones, associated with basic intrusives and extrusives. These are cut by dike-like bodies of acidic and intermediate porphyries and phaneritic intrusive volcanics. The basic igneous rocks have been largely altered to greenstones, or greenschists, by intense hydrothermal metamorphism on a regional scale. The sediments have been affected according to their composition. The quartzites and limestones have been rather thoroughly recrystallized, but otherwise remain relatively unaltered, except where the latter locally have been converted into marble or lime silicate rocks. The impure quartzose and argillaceous sediments have been transformed into phyllitic quartzites and metargillites, respectively.

Age

This metamorphosed igneous and sedimentary complex belongs to what Daly named the Anarchist Series, so-called because of the utter confusion of the structural relations among the various members (2). The threefold division of the Anarchist attempted by Waters and Krauskopf does not seem to have any valid application in this area (9). On account of their structural and lithologic resemblance to the Cache Creek series, if for no other reason, these rocks have been tentatively assigned to the Carboniferous by Daly (cf. above) and others (8). Also, collections of poorly preserved invertebrate fauna, taken from a graywacke somewhat to the southwest of this area by Waters and Krauskopf, were tentatively identified as Permian (9).

In the Conconully-Riverside area, south of the area studied by Waters and Krauskopf, Misch correlated a series of metasediments with the lower Anarchist, and has tentatively placed them in the Carboniferous (5).

Structure

Structural relations have been obscured by faulting, stretching, and mashing. The limestones have generally lost all trace of bedding, while the intrusive and effusive basic rocks have been so profoundly altered by both chemical and mechanical action that original tuffaceous or vesicular phases have been almost entirely obliterated, thus making it impossible to locate the top or bottom of any of the flows. The only member of the series of which Daly was able to determine the attitude of the true bedding is the metargillite (2). Fortunately, a fine outcrop of this rock occurs along the road from Chesaw to the border, just north of the Grey Eagle Mine. The bedding appears to coincide with the schistosity, and the attitude is nearly vertical, the strike being about north 35 east.

Structural elements apparently indicating plunge were noticed in the stratified quartzose and calcareous sediments marginal to the limestone pod just south of Chesaw and in an outcrop of phyllitic quartzite near Bolster Peak. These elements are lines formed by the intersection of axial planes of minor folds with the plane of the bedding or the schistosity. In both instances, these lines were inclined about 30 degrees to the southwest. It is believed that these structural elements represent a number of tightly compressed folds whose axes trend north 30-40 east and plunge moderately to the southwest. Because of the vigorous shearing, only some of the more competent or more plastic members still retain any vestige of the folding, while the incompetent argillites, as well as the highly competent brittle quartzites and the limestones generally, exhibit only the effects of shattering. Thus the predominant structural planes in the area are those produced by late shearing and faulting, while a subordinate set has developed as a result of jointing.

History

Into the metamorphosed Anarchist complex was intruded a group of acidic to intermediate volcanics grading into granular rocks, which latter are possibly analogous to Daly's Rock Creek granodiorite and diorite. The composition is evidently similar, although the porphyritic phases so common to this area are not mentioned by Daly (2). The author observed an outcrop of this Rock Creek granodiorite along the road about a mile north of the international boundary, but unfortunately no sample was taken for microscopic comparison. It did not, however, megascopically too closely resemble the typical tonalite of the author's area. If the acidic to intermediate granular intrusives and volcanics are contemporaneous with the Rock Creek granodiorite and diorite, then, according to Daly, they should be assigned probably to the Jurassic since he correlated the Rock Creek bodies with the Osoyoos batholith, which he believed to be of Jurassic age (cf. above). However, there is no actual evidence in either area.

At any rate, the Rock Creek bodies are pre-Oligocene, since the Kettle River formation overlies them uncomformably and has evidently obtained arkosic material from them (cf. Daly, above). Unfortunately, the age relations between the Kettle River formation and the acidic to intermediate intrusives and volcanics of the author's area could not be determined, since the former does not outcrop in the area, although an outcrop of graywacke, presumably belonging to the Kettle River formation, was observed in a road cut less than a mile north of the boundary. Thus, except for very dubious correlation with the Rock Creek bodies, no evidence exists to date these rocks more closely than late or post-Paleozoic.

Umpleby invokes another line of reasoning to place the acidic intrusives within the Mesozoic (8). He reasons that, since the intrusives are not schistose, they must be younger than the diastrophism which metamorphosed the Anarchist rocks, or presumably post-Paleozoic. Also they must be pre-Eocene, since he assumes the latter as the date of peneplanation, and a maximum of only about 1000 feet of cover exists between the highest observed elevation of the body and the peneplain surface -- scarcely enough to permit development of "the granitic texture characteristic of the mass unless the intrusion be dated as pre-peneplain." Granting the validity of this argument, the author is tempted to question the accuracy of the appellation "granite" as applied to the acidic igneous outcrops northwest of Chesaw. In the first place, the predominant texture of these rocks is aphanitic-porphyritic, placing them in a volcanic facies, while those samples that are equigranular or only quasi-porphyritic belong to a plutonic dike-rock facies. Thus, they do not, in general, have textures that would require much cover. In addition, the author found that all the "acidic" igneous rocks, with the exception of a few scattered outcrops of an obvious rhyolite porphyry, were extremely deficient in orthoclase and contained plagioclase of more basic composition than would normally be found in a granite. Thus, even the assignment of these rocks to the Mesozoic, it seems to the author, rests on very questionable grounds.

No Tertiary volcanics, such as the Midway volcanics north of the border and in the valley of Toroda Creek just to the east, were found in the area. Thus, the acidic and intermediate intrusives are the most recent rocks, and are only overlain by glacial and aeolian deposits.

Major Structural Features

No large faults could be determined for certain, due partly perhaps to the multiplicity of minor faults and shear zones. A spur projecting southeastward from Porphyry Peak is sharply truncated, suggesting a fault scarp. However, this spur might also be due to glacial action, although there is a divergence in rock type between the scarp face and outcrops directly below and adjacent to it. A brecciated zone of considerable width and linear extent trending southeast from near Strawberry Lake may indicate the presence of a major fault, but its true significance is obscured by lack of continuity of outcrop and by the complexity of relationships among the fragments constituting the breccia. The possibility that the valley of Myers Creek itself has been cut along a very large fault cannot be overlooked, especially in view of the divergence of rock types on the opposite sides of the valley.

ALTERED BASIC PLUTONICS AND MASSIVE AMPHIBOLITES OF PROBABLE IGNEOUS ORIGIN

These two ostensibly divergent lithologic types are classified under a single heading for the following reasons: (1) they are closely associated in the field; (2) they are petrographically related; (3) there are transitional types, which it would be difficult to assign to either group separately. These rocks form numerous small outcrops which are scattered in a few separate areas, each of which is of considerable extent. They have no particular surface expression and cannot be distinguished from the ordinary dense greenstone at any distance. Several contacts with the tonalite-dacite intrusives were noted. These appear sharp megascopically.

The less altered and therefore more distinct basic plutonics are described first. It is uncertain whether the different samples, exhibiting various degrees of alteration and different textures, are all derived from one parent type, or whether they may represent several orthomagmatic derivatives, possibly different facies of one gabbroic intrusive. In any case, several samples indicate rather positively a gabbroic type as the parent rock. These are characterized by blasto-ophitic textures, in which large turbid, sericitized, and often saussuritized, mostly subhedral laths of plagioclase lie embedded in anhedral masses of pyroxene. Sometimes the pyroxene forms stout subhedral prisms. Pyroxene is actually present in only a few of the samples studied, and even in these, hornblende can be seen replacing it along its cleavage planes (Plate 4). Most often, only hornblende or actinolite pseudomorphs remain to indicate the former existence of pyroxene (Plate 6).

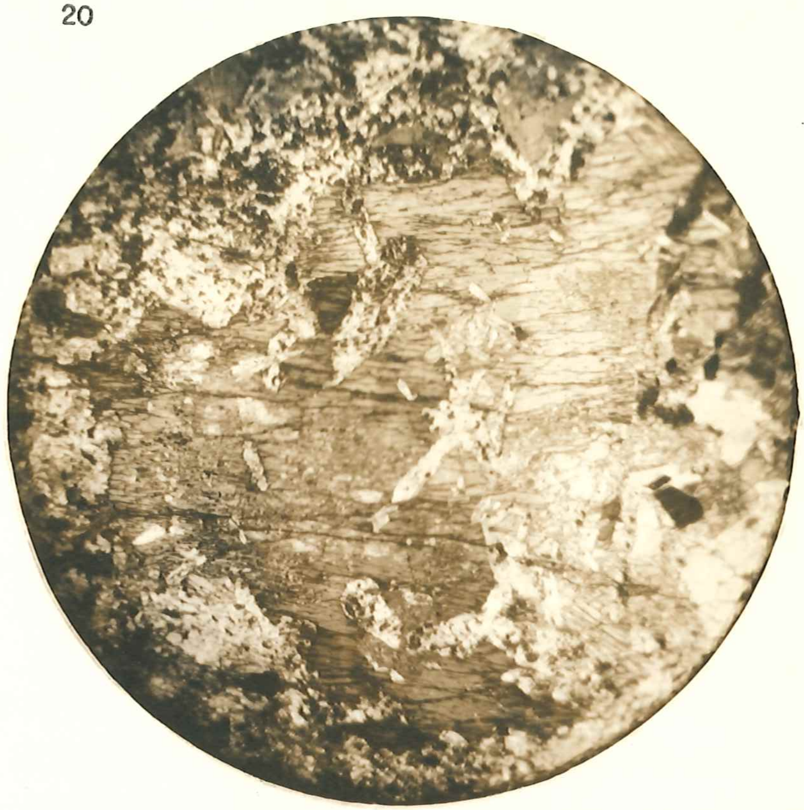


Plate 3. Hornblende porphyroblast in ortho-amphibolite.

16X, crossed nicols

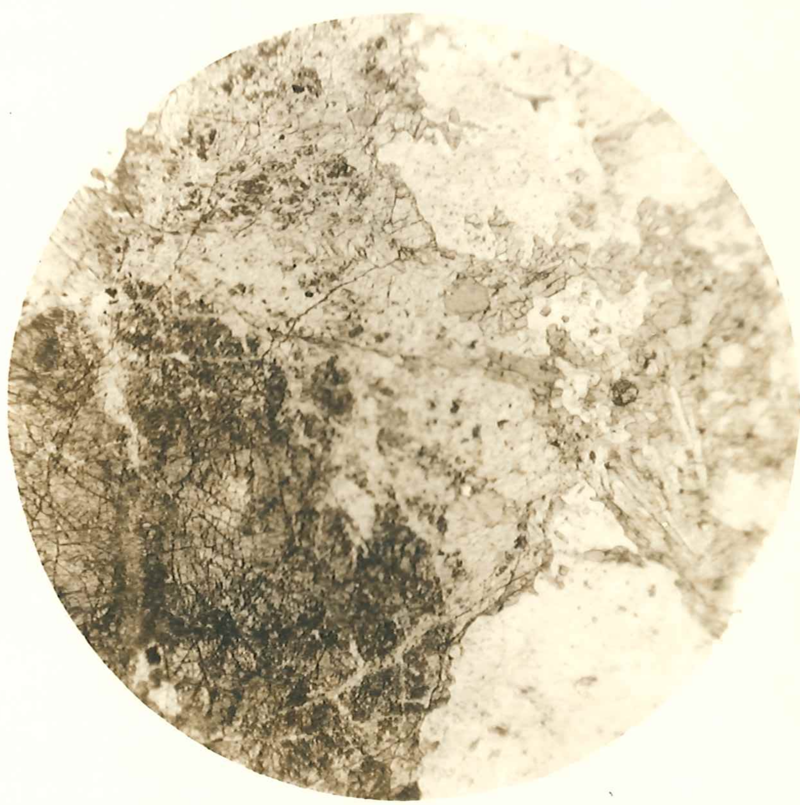


Plate 4. Hornblende replacing pyroxene in basic plutonic rock.
Hornblende - h, pyroxene dark 32X, plane light

The plagioclase was tentatively identified as calcic andesine, but heavy saussuritization of the laths leaves this determination subject to doubt. In some cases, replacement by carbonate along cleavage traces is visible, and this decalcification has produced small, clear patches, evidently albite, some of which are marginal to large plates. Hornblende, in addition to forming pseudomorphs after pyroxene, is often present as small, fresh idioblastic grains, which form a sort of pavement or mosaic.

Thus the alteration of these rocks seems to include two processes: (1) there was breaking down of the primary minerals, exemplified in the decomposition of plagioclase into masses of sericite, carbonate, and clinozoisite; and the breakdown of pyroxenes into hornblende or uralite, with the resulting by-products carbonate, clinozoisite, and chlorite; (2) there was a certain amount of regeneration, characterized by crystalloblastic and porphyroblastic hornblende, apparently replacing the masses of carbonate and sericite which were left by the breakdown of plagioclase. The extent of regeneration by metamorphic recrystallization varies from place to place.

In some of these rocks, decomposition has gone so far that the exact nature of the original rock can only be guessed. These are usually composed of vaguely defined sericitic patches and "ragged" columnar pseudomorphs of actinolitic material, carbonate, and chlorite. Sometimes, however, these large pseudomorphs still consist of strongly pleochroic hornblende. Some of them have been deformed to porphyroclasts (Plate 5). The only remaining traces of plagioclase grains are heavy concentrations of sericite and carbonate. Frequently, there is a considerable amount of iron ore in scattered grains, often as skeletal frameworks suggesting ilmenite, and associated with pinkish opaque masses, presumably leucoxene (Plate 7). Biotite is

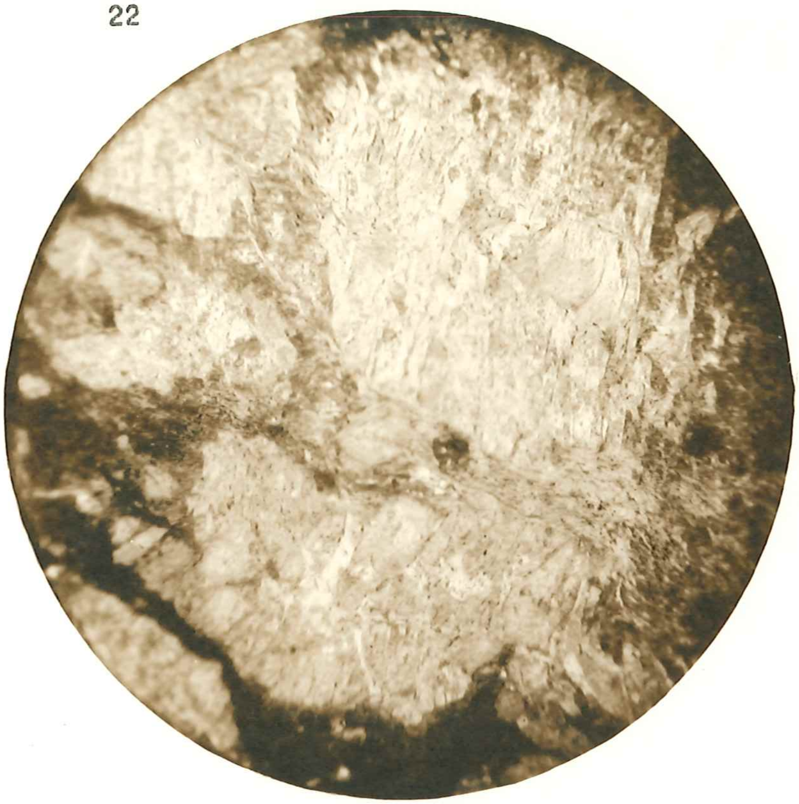


Plate 5. Large uralite porphyroclast in altered basic plutonic.
16X, plane light

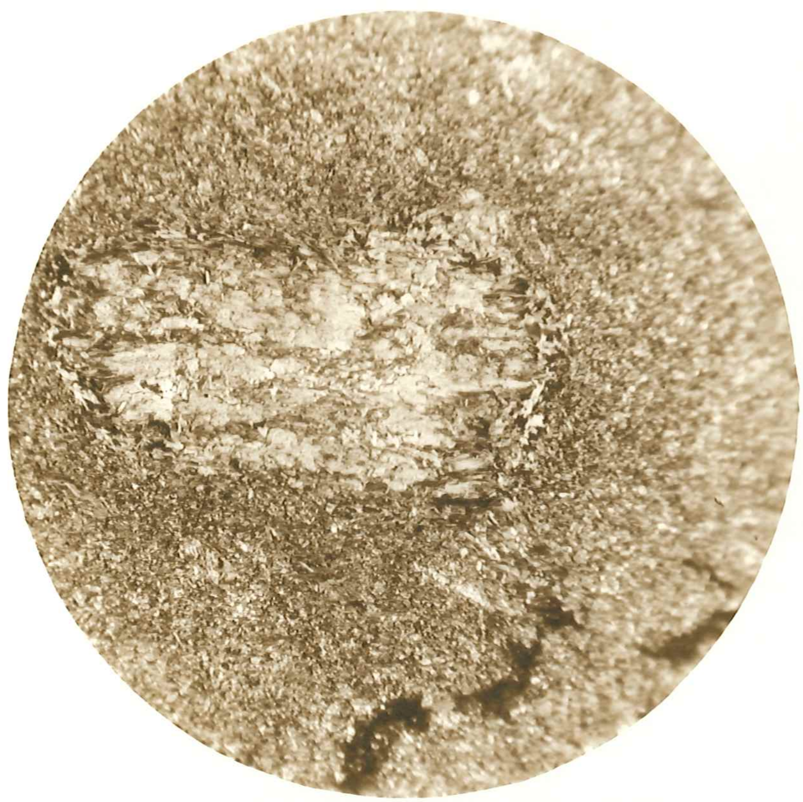


Plate 6. Greenstone, showing large uralitic pseudomorph, now partially biotitized. 32X, plane light

Plate 7. Skeletal ilmenite in altered basic plutonic.

16X, plane light

occasionally present in the more altered rocks. Sometimes it occurs in aggregates of randomly oriented plates, replacing uralitic amphibole, and in other cases it forms fine granular concentrations. Whether this biotitization is deuteric, like that in the tonalite-dacite group, or the result of later hydrothermal alteration, is uncertain.

In extreme cases the igneous textures, supposed to have been originally present, have been totally destroyed, and the actinolitic material forms a sort of mat with an occasional pseudomorph-like, more coarse-grained aggregate. These rocks become indistinguishable from the "typical" actinolitic greenstones which constitute such an overwhelming portion of the described area.

The associated amphibolites, insofar as they differ from the altered basic plutonics just described, are generally massive and fine grained. Some are composed of xenoblastic grains of fresh green hornblende and albite, forming a mosaic texture (Plate 8). In others, there appear to be two generations of feldspar, and sometimes two generations of hornblende as well. These latter apparently constitute a transitional type between the fully recrystallized, more typical amphibolites mentioned above, and the basic plutonics described in the preceding paragraphs. In these transitional rocks, amongst the small, fresh, clean, xenoblastic grains of albite, lie large, turbid, often digital masses of sericite, some of which contain inclusions of hornblende. It is believed that these sericitic masses represent the original plagioclase grains of the gabbro, which have become partially decalcified, although what happened to the liberated calcium is not clear since little carbonate or epidote is present. Moreover, the inclusions of hornblende in the sericitic masses are difficult to explain under this hypothesis.

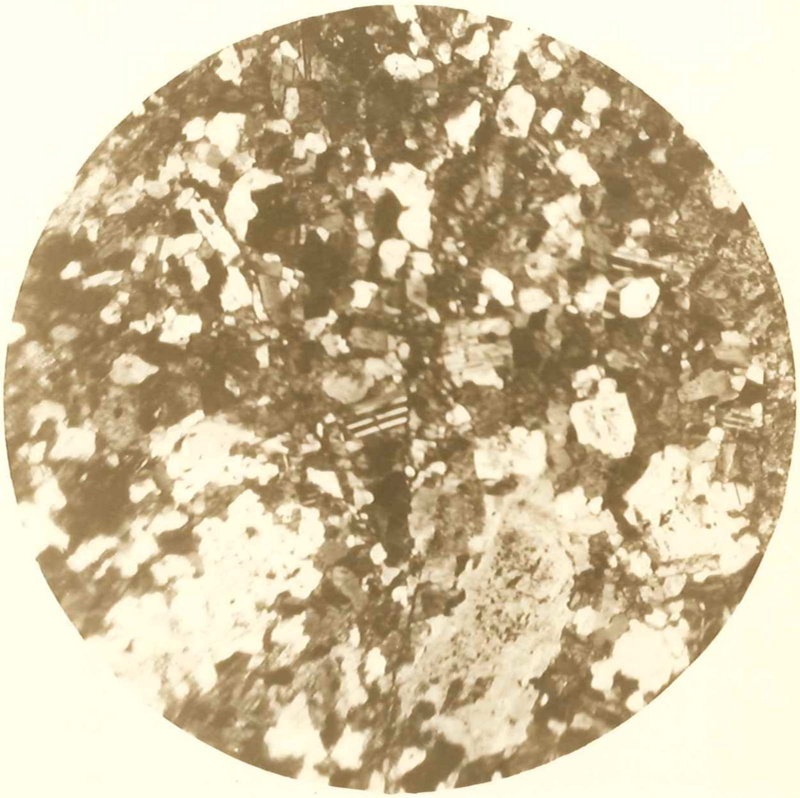


Plate 8. Ortho-amphibolite, showing albite hornblende mosaic and larger altered plagioclases, believed to be relicts from original basic plutonic.

32X, crossed nicols

It may be that, during the albitization of these large decomposed feldspars, crystalloblastic hornblende developed in the more calcic, perhaps residual, areas, utilizing the liberated calcium plus mafic material either included in the original plagioclase or possibly introduced. The clear albite grains are generally much smaller than the sericitic patches, but there are also intermediate sizes. The question of the age relationships of the sericitized masses to the albite-hornblende mosaic is difficult to answer. If we assume that the sericitization is a final stage, or at least later than the hornblende-albite mosaic, then the freshness of the albite must be accounted for. It may be due to differential alteration, the large sericitic patches representing the residual more calcic parts of the original plagioclase which were more easily affected by later hydrothermal action.

Some samples exhibit large porphyroblasts of hornblende as well as a fine-grained hornblende-albite mosaic (Plate 3). The presence of these porphyroblasts, presumably originally pseudomorphic after pyroxene, is further evidence of the close relationship between the amphibolites and the basic plutonics.

The former existence of ultra-basic plutonics, in addition to the gabbroic plutonics discussed, is indicated by a few widely separated outcrops of carbonatized serpentine. This occurs as a carbonate-antigorite schist, with the antigorite partly altered to talc.

Contact Relationships

In several places, contacts between the amphibolites and the younger tonalitic-dacitic rocks were observed. The only noticeable effect on the amphibolites is the increase in size of the hornblende grains, forming a narrow zone of large porphyroblasts, oriented crudely parallel to the contact. A sample from one outcrop showed the amphibolite in apparent fault contact with a rock consisting of euhedral prehnite and carbonate, with a crude band of fine-grained clinozoisite along the contact. This rock is presumably a hydrothermally metamorphosed limestone. Here again, as mentioned before in the case of a dacite-greenstone contact, is evidence that the contacts along which movement has occurred provided easy access for hydrothermal, probably siliceous solutions. That there was a high silica content in the solutions is attested by the silicification of the tonalitic rocks where they were found in contact with the amphibolites.

It might be suggested that the diorite previously described is just an unaltered representative of one of the "meta-gabbros." An intrusive contact between the diorite and the amphibolite would tend to disprove this notion. Unfortunately, no such contact was found. However, about three miles north of the amphibolites described above, there occurs a contact between what appears to be one of the gabbroic rocks, and another rock type resembling the amphibolites. Whether this represents a bona fide contact or possibly just a facies change is questionable. A thin section of this contact shows: (1) a rock consisting of large plates of feldspar, some euhedral, and of large masses of spongy brown hornblende, in a "groundmass" of sericite, carbonate, clinozoisite, and apatite; and (2) an equigranular fine-grained rock of apparently similar composition, except for the absence of the large brown hornblende. The large hornblendes in the "gabbroic" rock are obviously porphyroblastic, and seem to be replacing areas of sericitic matter. These hornblendes could be deuteric after pyroxene.

They, in turn, show partial alteration to a green hornblende, weakly pleochroic. This faintly colored secondary actinolitic hornblende is also present as crude columnar plates. There is considerable magnetite in scattered irregular masses. This is interesting, in view of the fact that hornblende requires so much more iron than pyroxene. Thus any excess iron in the altered rock -- assuming that the hornblende is in fact pseudomorphic after pyroxene -- suggests that there was a large amount of magnetite in the original rock. No quartz is present. There seems to be little doubt that the rock with the large hornblendes and feldspars was originally a basic igneous type.

The origin of the fine-grained rock is less certain. Resemblance to the amphibolites previously described is not too close. The hornblende grains are neither deeply colored nor idioblastic. Instead, they are "ragged" and weakly pleochroic. Albite is not well developed, although a few fresh grains were noted, and albitic zones, marginal to the sericitized feldspars, are common in this rock as well as in the gabbroic rock. It may be that the temperature was too low to permit the development of the green hornblende so characteristic of the amphibolites from the other areas.

Another specimen from an outcrop about 100 feet north of the one mentioned above showed the same brown hornblende, partly altered to green hornblende, in both large and small idioblastic grains, and large, extremely poikioblastic masses, together with much sericite and incipient albite. This sample also contains later retrogressive epidote and chlorite. Moreover, instead of being massive, this sample shows distinct helizitic structure (Plate 9), indicating that the growth of the large hornblende porphyroblasts was preceded by deformation. This eliminates the possibility that

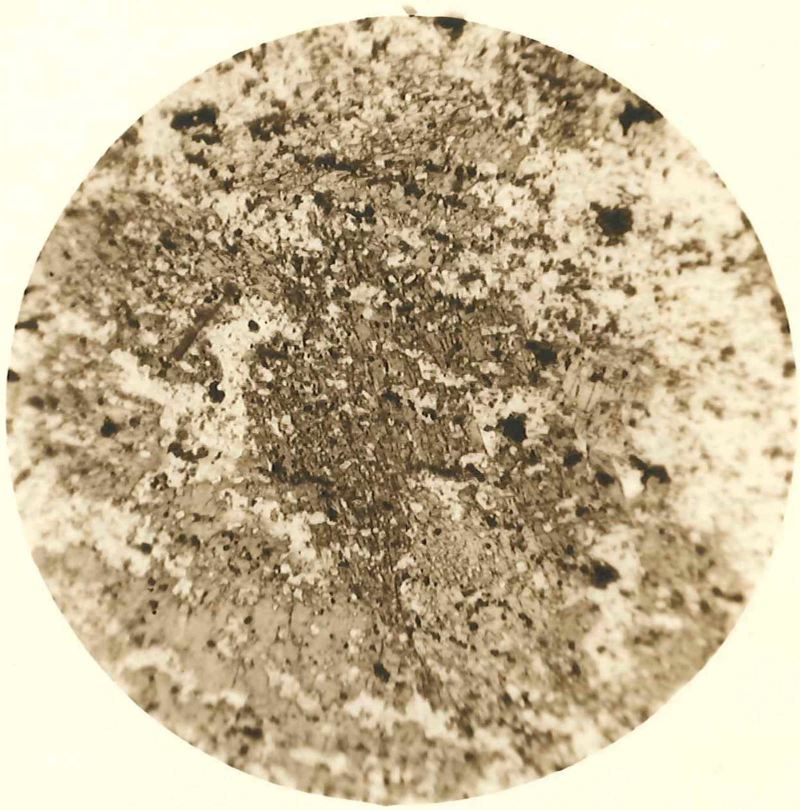


Plate 9. Amphibolite of doubtful origin, showing hornblende porphyroblasts and helizitic structure.

32X, plane light

these hornblendes are deuteric-uralitic. It follows, then, that for these rocks, the whole case for a gabbroic origin is weakened.

In another part of this same area, one of these amphibolites was found in contact with a quartzite. The only possible contact effect is a considerable amount of silicification within the amphibolite, quartz replacing the heavily sericitized feldspars.

ACTINOLITIC GREENSTONES

A preponderant part of the area consists of dense, tough, greenish to grayish rocks, generally massive except where they have been sheared. Field relations offer few clues as to their possible origin. Contacts with other rocks were seldom seen and of little value to interpretation. In many places, these rocks could be traced into the impure quartzose sediments. Certain rocks appear to be transitional members, but this is not definite. It is very probable that these rocks do not constitute a genetic unit, but they will be treated as a unit simply because no reasonable basis for differentiation exists.

The majority of these rocks are believed to be weakly metamorphosed basic volcanics, and many of them can be demonstrated to have such an origin. Some of the outcrops mapped as undifferentiated greenstones could just as well have been classed with the altered basic plutonics and amphibolites of probable igneous origin. Indeed, it is strongly suspected that some of the amphibolites found in contact with felsic intrusives are merely greenstones, metamorphosed by the higher temperatures prevailing near the contact. There were, however, some cases in which apparently unaltered greenstones were found in contact with acidic intrusives. This does not necessarily vitiate the contact metamorphic theory of genesis for some of the amphibolites, since Reid (6) found the same lack of uniformity of contact effects on greenstones in the Wallowa Mountains of Oregon and attributed this to differential heating due to fracturing.

In some places strong shearing has made the greenstones extremely fissile, causing them to weather into paper-thin sheets, but usually they have a rough, sometimes blocky weathering surface. Topographic expression is largely controlled by glaciation. Cataclasis and hydrothermal action have effectively obscured their genesis.

Petrography

In thin section, many of the samples suggest a fragmental texture, thus indicating probable derivation from a tuff or breccia, perhaps a tuffaceous agglomerate. Very few are homogeneous, and they are often "patchy." These patches may be amphibolitic, quartzo-feldspathic, actinolitic, biotitic, sericitic, or even so fine-grained as to appear isotropic. One thin section consists of fragments of altered volcanics with crystallites of feldspars and uralitized pyroxene in a devitrified matrix. Relict vitrophyric and trachitic textures are not unusual. Several sections show twinned lath-shaped microlites of plagioclase in roughly parallel arrangement, embedded in a dense groundmass. Generally these were found only in patches.

Examples of amygdaloidal structure are frequent. In one case, microlites of plagioclase form a trachitic texture in the groundmass, while roughly spherical amygdules of quartz, usually with an outer rim of magnetite and chlorite, are randomly distributed. In this rock, the quartz is remarkable for its pronounced undulatory extinction. It is apparently later than the magnetite, having filled the vesicles after the magnetite and chlorite had been deposited as an outer layer. Magnetite is widely disseminated through this thin section as globulites, and is locally concentrated around the outer margin of amygdules in the form of cumulites. A second generation of quartz is cryptocrystalline in character, forming veinlets, frequently with chlorite, that transect the amygdules.

These rocks roughly comprise two mineralogical varieties: (1) rocks rich in actinolitic hornblende, and (2) rocks rich in chlorite plus carbonate or clinozoisite (Figure 3). In either case, the high ratio of Mg to Ca, indicated by the preponderance of actinolite and chlorite, is strong evidence for an igneous as against a sedimentary origin. By far the larger number of samples show actinolitic hornblende as the dominant mineral. This occurs, characteristically, as fibrous or plumose aggregates and tiny acicular prisms, which often constitute a dense sort of mat, containing scattered clusters of other minerals. In some cases, there are occasional columnar pseudomorphs, now composed of almost colorless amphibole; sometimes this amphibole is stained a yellowish-brown by some pigment. These pseudomorphs are suggestive of phenocrysts in what once was a basic porphyry. Some samples show porphyroblasts of fresher, bluish-green hornblende, apparently corresponding to the blue-green hornblende of Turner's albite-epidote amphibolite facies (cf. 7).

Biotite is frequently present as scattered concentrations of fine, almost incipient material, and also occasionally as larger, in one case euhedral, plates. These plates are usually found in aggregates, forming pseudomorphs after hornblende, bluish-green vestiges of which frequently remain. In one instance, biotite not only forms pseudomorphs after hornblende, but is also widely disseminated through the rock mass. In fact, it is the dominant mineral in this sample, and yet the texture very closely resembles that of the typical dense actinolitic greenstone. All the evidence

Fig. 3. Mineral Assemblages Characteristic of the Greenstones

Assemblages	Common	Fre- quent	Occa- sional	Rare
Actinolitic hornblende predominant; subordinate carbonate, chlorite, mica or epidote	X			
Chlorite predominant, with subordinate carbonate, mica or epidote		X		
Actinolite (or actinolitic hornblende), carbonate, chlorite, and sericite, biotite or epidote in varying proportions	X			
Actinolitic hornblende with subordinate biotite		X		
Sericite predominant; subordinate actinolitic amphibole; accessory chlorite or carbonate			X	
Biotite, sericite, and carbonate				X
Carbonate and subordinate chlorite				X
Epidote with subordinate chlorite				X

indicates that this is a biotitized greenstone. If this is true, then biotitization in these rocks, at least, is the result of later hydrothermal metamorphism. This implies slight local potassium metasomatism, for which there is supporting evidence in the form of grains of microcline and microperthite, which were noted in several sections. Also, quite a few samples contain considerable quantities of sericite.

Iron ores are usually present in abundance. Magnetite is most common, and occurs as irregular grains and stringers, sometimes as small euhedra. Frequently, there is a bluish-gray metallic mineral in the form of small rods and skeletal crystals, which is assumed to be ilmenite, especially since it is often associated with a pinkish opaque mineral resembling leucoxene. Sulfide is often present also. These iron ores sometimes constitute as much as 30% of the rock.

In addition to the microlites of plagioclase and the amygdules of quartz already described, quartzo-feldspathic material is found in considerable amounts in lenticular patches and disseminated throughout the rock. Generally, it is so fine and so obscured by the mafic constituents that it cannot be identified, although occasionally plagioclase grains showing multiple twinning can be detected.

Those rocks in which chlorite associated with carbonate or clinozoisite predominates over actinolite do not differ markedly in other respects. The chlorite is either disseminated or occurs in patches resembling pseudomorphs. Carbonate occasionally forms curious slender euhedral prisms, randomly oriented. They are obviously pseudomorphs, but after what mineral is not known. Sericite is somewhat more common in these rocks, biotite somewhat less so. The plagioclase grains in most cases could not be exactly identified, but, in some rocks, an albitic composition could be determined.

Although lumped together under the heading "greenstones," many of these rocks are somewhat schistose, and should, perhaps, more accurately be termed greenschists. Some of these merely show a slight preferred orientation of the platy minerals, while others are distinctly banded due to shearing and resulting metamorphic differentiation. Gentle microfolding is present in some of the rocks, and in others these miniature folds have become tightly compressed, with secondary shear planes developing parallel to the axial planes. Sometimes the bands are sharply displaced by these late shears and fine examples of drag can be seen. Still later is a more irregular fracturing. Recrystallization due to hydrothermal metamorphism seems to have outlasted the first period of deformation, and, in some cases, has continued through the final fracturing. Late veinlets containing actinolite, chlorite, carbonate, or albite are common.

Cataclastic structures are fairly common, and some of these mylonitized rocks deserve special mention. These rocks occur in the highly sheared zones mentioned in the opening paragraph, but owing to the difficulty involved in grinding, not many sections of them were made. They are typically banded, and the feldspar or hornblende grains are drawn out into lenticular shapes. Individual grains show highly undulose extinction, or have even been crushed into mortar. Some of the mortar has been partially recrystallized. A mineral which appears to be biotite has been smeared out into thin films. In one section, sericitic bands contain pods or lenses of quartz and actinolitic hornblende which have apparently recrystallized after the shearing.

METASEDIMENTS

Next to greenstones, weakly metamorphosed siliceous, calcareous and argillaceous sediments make up the largest lithologic group in this area. This group of rocks includes quartzites and impure quartzose sediments, metargillites, biotite hornfelses, limestones and some calc-silicate rocks. The limestones and the purer quartzites can, of course, be easily differentiated from the greenstones, but many of the impure siliceous sediments are actinolitic or biotitic, and the higher the mafic content, the more difficult it is to distinguish them from certain types of greenstones. Along the strike, as well as across it, there seems to be no sharp line of demarcation between these rocks and typical greenstones.

Some of these rocks may have occurred in primary lenses, and some gradational types probably were tuffaceous sediments. Moreover, these rocks evidently have suffered tectonic interlensing and intershearing, which was accompanied by a considerable transfer of material, so that contacts often are no longer recognizable. Rocks of apparent transitional character proved to be of little help, even in thin section, due perhaps to the presence of tuffaceous shales and other clastics contaminated by volcanic material.

(1) Quartzites and Impure Quartzose Metasediments

These rocks generally outcrop as long low ridges, or ribs with a northeasterly trend, the purer varieties having the more pronounced topographic expression. They are more numerous in the northern part of the area, where they constitute at least half of the exposures. Toward the south, they become less common, and are found only as occasional lenses in the greenstones. The purest quartzites are white or bluish gray, massive, and somewhat vitreous. Mostly, they are so fine-grained as to resemble chert. Locally, they are conglomeratic, but this is not generally apparent except under close scrutiny, because the pebbles are almost entirely siliceous and thoroughly recrystallized. Where the quartzites grade into greenstones, they become impure and more schistose, with thin micaceous, and "dirty," probably carbonaceous, bands. In certain areas, mottled, heterogeneous, brecciated, very fine-grained quartzose rocks with low inconspicuous outcrops and a blocky weathering surface were found to be highly feldspathic. The micaceous and feldspathic members were evidently derived from argillaceous siltstones, possibly including tuffaceous or arkosic layers.

Petrography

Petrographically, the pure quartzites have a very fine-grained groundmass, with more coarse-grained, apparently recrystallized, lenses and veinlets. These veinlets frequently contain carbonate and/or pyrite. The recrystallized quartz in the veinlets often shows comb structure, while the pyrite is frequently euhedral, indicating that these fractures remained open for some time. Several periods of brecciation can be traced, since each successive set of fractures displaced earlier veinlets. These successive periods of fracturing were each accompanied by a period of mineralization, deposition of pyrite being preceded as well as followed by precipitation of quartz. Calcite is usually the last mineral to form.

The conglomeratic members contain sub-angular pebbles of quartzitic chert. The rocks comprising the pebbles show a varying grain size.

Mostly they are extremely fine-grained with scattered larger grains. The grain size of both pebbles and matrix is so fine that a chert derivation seems very likely.

The phyllitic quartzites and quartzitic schists are characterized by irregular swirling or undulating bands of sericite, biotite (or stilpnomelane?), chlorite, or sometimes actinolite, between wider quartz layers. Usually, some of the sericite is coarse enough to be classed as muscovite. The biotite is incipient or extremely fine, and in some samples very closely resembles stilpnomelane, although it could not be positively identified as such. This biotitic matter is often intimately associated with chlorite, and sometimes one grades into the other within the same band. Those members in which actinolite is plentiful may possibly represent dolomitic or tuffaceous layers in the original sediment.

Unusual accessory minerals, each found in only one thin section, are garnet and tourmaline. The garnet is presumably spessartite. It occurs in a phyllitic quartzite, which is composed of swirling irregular bands of biotite (possibly stilpnomelane) and of closely associated chlorite, of wider zones of fine-grained quartz, and of bands of sericite. It forms subhedral grains, which are slightly larger than the quartz grains. It is liberally scattered through the biotite-chlorite bands, and is restricted to them. Tourmaline was found as small columnar aggregates in a banded quartzitic schist, consisting of about 70% very fine-grained quartz, streaks of smeared-out incipient biotite with some carbonate, and scattered tiny prisms of actinolite.

At least two periods of later shearing can be observed in the phyllitic quartzites and the quartzitic schists. During the first period, fine chevron folds developed, followed by shearing along the axial planes of the folds (Plate 10). This resulted in smearing the micaceous layers into streaks and thin bands. Then, renewed shearing stress caused cross fractures with displacement of the bands. Some recrystallization followed, and the newly formed fractures appear to have aided in some redistribution of some of the mineral matter. Concurrently, some silica was apparently introduced, since coarser, crystalloblastic quartz follows some of the shearing planes. Sometimes, shearing seems to have outlasted crystallization, as quartz porphyroclasts have developed. Some of the sericite must also have recrystallized after the first period of deformation, as coarser plates of muscovite are oriented with their long axes normal to the bands. Some carbonate and some feldspathic material also seem to have been introduced at this time. The evidence for some feldspathization will be discussed below.

(2) Weakly Metamorphosed Argillites

These metargillites vary in color from greenish gray to dark gray or almost black. Weak slaty cleavage is fairly characteristic, but some of the rocks are massive and have a somewhat conchoidal fracture. Their outcrops are inconspicuous except where glaciation has locally accentuated them. Only in one place, just north of the Gray Eagle prospect along the road, were they observed to cover any appreciable area. Here, they strike north 30-40 east and stand nearly vertical.

Actually, these rocks do not form a distinct group, but are gradational into the impure quartzites on the one hand, and the biotite hornfelses on the other. They differ from the impure phyllitic quartzites in having

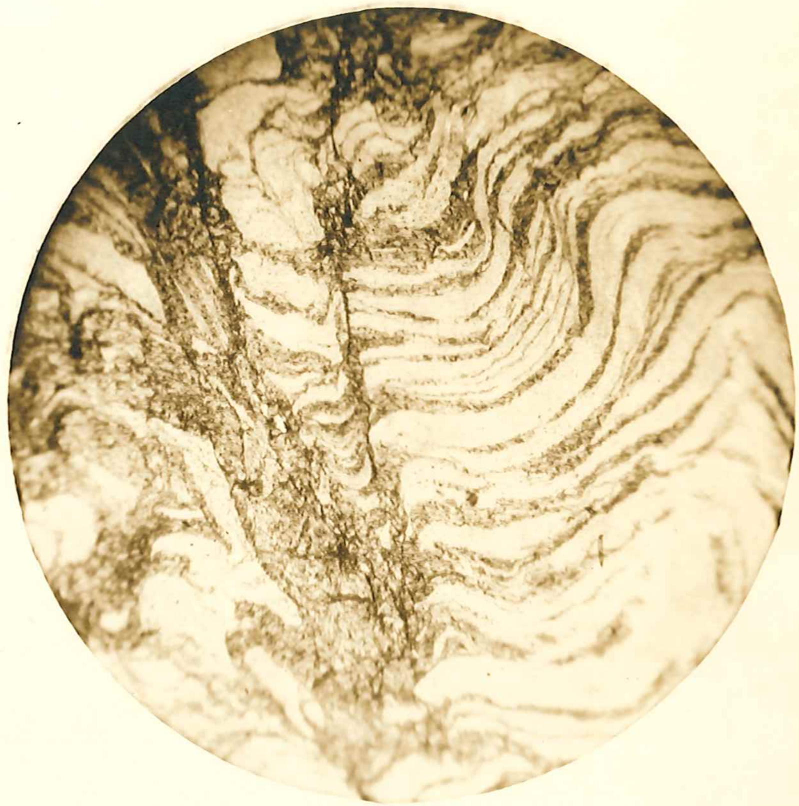


Plate 10. Chevron folds in phyllitic quartzite, with secondary shears developing along axial planes.

16X, plane light

a smaller quartz content and a larger proportion of mica. They differ from the hornfelses by having less biotite and feldspar, and in being generally more schistose, although not sufficiently schistose to be called phyllites. Some of these rocks, however, are more phyllitic in character and may be designated phyllitic argillites or phyllitic slates. As a whole, the rocks of the present group display rather weak and fine-grained recrystallization, which was induced by hydrothermal action and partly aided by penetrative deformation. These rocks are presumably derived from argillaceous siltstones, possibly with tuffaceous layers.

Petrography

Petrographically, these rocks are difficult to describe because of their heterogeneity. Some contain as much as 60% quartz with subordinate quantities of incipient mica or actinolite. These could almost as well be grouped with the phyllitic quartzites. Others are predominantly micaceous, with minor amounts of quartz. In some, biotite (or stilpnomelane?) is dominant, while in others sericite is the chief mineral. Still others have a high percentage of actinolite. If they have anything in common, it is their grain size, which is extremely small. In many cases they show only incipient recrystallization. A sample from the large outcrop mentioned above is composed of very fine-grained sericite and carbonate, dotted with rounded "knots" of quartz in the form of "glomeroblasts," or clusters of small, variously oriented anhedra. The sericitic "groundmass" of this rock shows marked preferred orientation. A specimen from one of several outcrops in the northern part of the area shows a large proportion of cryptocrystalline quartz in lenses, and crystalloblastic quartz in veinlets, and some fine greenish matter, possibly incipient actinolite, also considerable carbonaceous material. A sample from another outcrop nearby contains a substantial amount of small lath-shaped feldspar, which is mostly confined to one layer. This rock contains, in addition, about 50% fine-grained quartz, biotite-magnetite bands, and scattered grains of actinolitic hornblende. It is believed that the feldspars may represent a layer of crystal tuff, and that the laths may be relicts.

As in the impure quartzitic rocks, two periods of deformation after the formation of the original schistosity are evident. Banding, produced by shearing, and smeared out carbonaceous matter exemplify the first, while the second is indicated by cross fractures or secondary wrinkles, developed normal to the original schistosity. Crystallization, in some cases, has outlasted this later deformation. One thin section is characterized by a blasto-mylonitic texture.

(3) Biotite Hornfelses

Although these rocks are likewise derived from more or less argillaceous sediments, they differ in a few respects from those just discussed. They contain biotite as the principal mineral, with subordinate fine-grained quartzo-feldspathic material. They are generally massive or only very slightly schistose. They do not outcrop in any well-defined areas, although their outcrops are somewhat concentrated at the summit of Strawberry Mountain and near the head of the draw southeast of Porphyry Peak.

Petrography

In thin section, crystalloblastic feldspar can usually be seen. Often it is concentrated in segregations, which occasionally are poikioblastic.

It is evidently sodic plagioclase which could not be more closely determined. It is mostly untwinned, but sometimes shows albite or carlsbad twinning. Some fine-grained quartz is generally present. Chlorite and/or actinolitic hornblende frequently occur as disseminated flakes or grains, and in veinlets. Scattered tiny grains or prisms of epidote and/or apatite are sometimes found. Magnetite as stringers or irregular masses is very common.

In cases where some deformation is evident, much of the crystallization is apparently post-foliation. Biotite, actinolitic hornblende and chlorite grains individually show little preferred orientation, but are, as a rule, crudely arranged in bands, thus suggesting mimetic recrystallization of compositional bands. Several periods of brecciation are often prominently displayed.

(4) Limestones and Calc-silicate Granulites

Of all the metasediments, the limestones are the most distinctive, although not the most numerous. They occur as pods and lenses of varying dimensions throughout the greenstones. Where they are relatively unmetamorphosed, they are light gray to bluish in color, fine-grained, and unfossiliferous. They are strongly sheared and jointed. At the southeast corner of the area, where the Oroville-Chesaw road makes a right angle turn to the west just south of the village of Chesaw, is a prominent bluff consisting primarily of this grayish-blue sheared limestone, with intercalated thin argillaceous beds. A thin section from a specimen of the latter showed it to be composed of fine-grained, but recrystallized quartz and scattered, slightly larger, euhedral rhombs of carbonate.

The attitude of these beds appears to be conformable with the surrounding greenstones which trend north 35-40 east. Certain elements, which appear to be the axes of minor folds, plunge 30-40 degrees to the southwest. This conforms with the plunge observed on a fold axis in a quartzitic schist near Bolster Peak.

Where the limestone is found as thin lenses in the greenstone, and where small pods have been locally subjected to considerable stress under higher temperatures, it has been recrystallized into a white marble. In a few very localized instances, calc-silicate minerals, indicating a comparatively high temperature, have developed. These rocks consist predominantly of diopside and garnet, which presumably is a grossularite-andradite mixture. Only one thin section showed the presence of pyroxene. In this section, the garnet was euhedral, with sharp, straight faces, and strikingly zoned (Plate 11). Generally, this higher grade facies has been largely obscured by a superimposed retrogressive greenschist or epizonal facies, consisting of epidote, forming at the expense of garnet (Plate 12), of carbonate and chlorite. Considerable plagioclase is present, but its composition could not be determined.

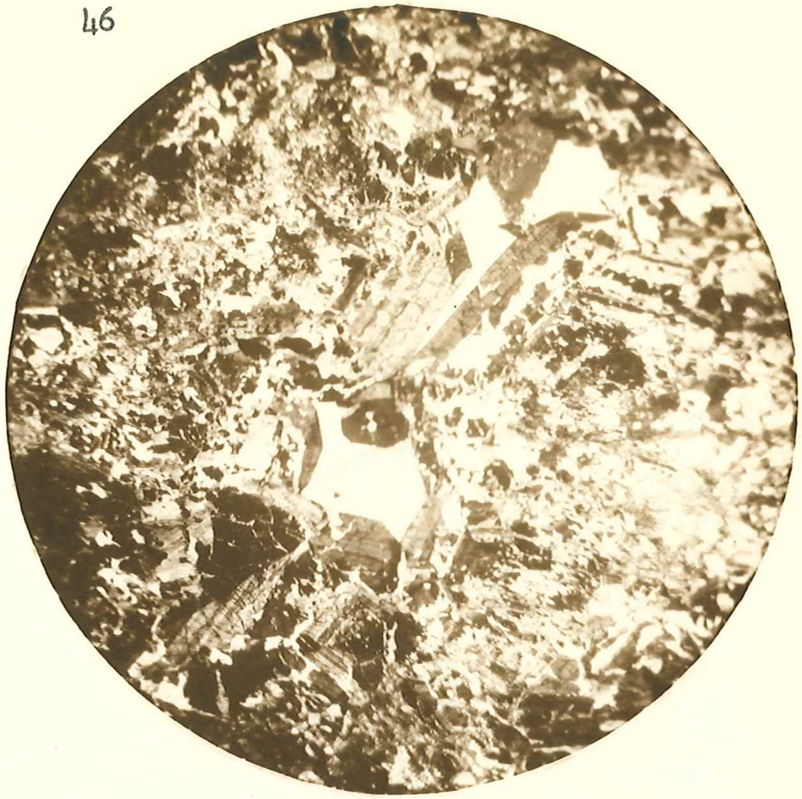


Plate 11. Zoned garnet, slightly anisotropic, with euhedral borders, largely replaced by epidote, in calc-silicate rock.

16X, crossed nicols

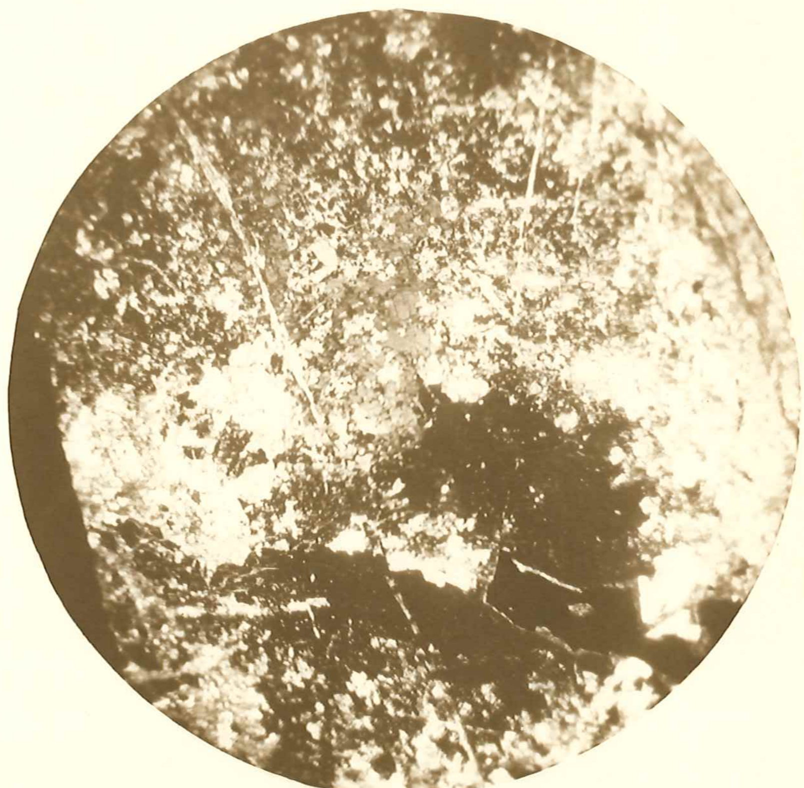


Plate 12. Epidote (e) replacing garnet (dark) in calc-silicate rock.
16X, crossed nicols

BANDED EPIDOTE AMPHIBOLITES

In the extreme northeastern corner of the area is a series of rugged outcrops, trending northeast and forming steep cliffs facing southeast. They consist of banded epidote amphibolite, associated with grayish green to whitish quartz-carbonate schists and highly recrystallized quartzite. These rocks represent a higher grade of metamorphism than is generally found in other parts of the area. They also clearly show two superimposed facies, a main epidote amphibolite facies, and a retrogressive greenschist facies.

These amphibolites, in contrast to those discussed previously, can be definitely labeled para-amphibolites, both by virtue of field relationships and petrographic evidence. They are clearly conformable with and gradational into the quartz-carbonate schists and quartzites.

In thin section, they are seen to consist mainly of bands of hornblende and epidote. The hornblende grains are pleochroic as follows: X = yellow green, Y = olive green, Z = dark green. They are fresh and anhedral. They are partly aligned in the direction of schistosity. Generally, the hornblende bands are not sharply differentiated from the epidote bands, and frequently the grains are intermingled. The hornblende grains are manifestly in equilibrium with the epidote. Together with the epidote, they constitute anywhere from 70 to 90% of the rock.

Quartz occurs in narrower bands or lenses, sometimes with plagioclase and carbonate, sometimes as a fine granular mosaic with small anhedral garnet grains. Quartz also forms cryptocrystalline cross-cutting veinlets. The granular quartz associated with the garnet forms layers that are obviously of sedimentary origin, while the quartz occurring with the plagioclase and carbonate is plainly introduced. Small, fresh anhedra of plagioclase, believed to be albite, although not positively identified as such, are scattered among the quartz and carbonate. There are also patches of turbid sericitic material, presumably decomposed feldspar. Sphene is a common accessory, sometimes granular and roughly concentrated in narrow bands, frequently as fine euhedra. Scattered grains of apatite are usually present also.

Garnet and hornblende both show partial chloritization (Plate 14). In one sample, acicular actinolite forms a kind of mat in a felsic area, the needles well aligned, but at an angle to the main foliation (Plate 13). Thus the retrogressive assemblage representing the low grade superimposed metamorphism seems to have formed under stress from a different direction than that from which the amphibolitic facies resulted.

A brief history of these rocks as indicated by petrographic evidence is: (1) a main period of deformation under mesozonal conditions, during which the assemblage hornblende, epidote, garnet, sphene was formed, crystallization of the hornblende somewhat outlasting deformation; (2) a second period of deformation, under stress from another direction, characterized by shattering of the sphene; introduction of quartz under partial replacement of epidote; development of actinolite; albitization of older feldspars; partial chloritization of hornblende and garnet; (3) still later stress, resulting in the fracturing of the quartz, with introduction of carbonate and cryptocrystalline quartz.

The quartz-carbonate schists consist predominantly of fully recrystallized quartz with pronounced collective crystallization and thin bands

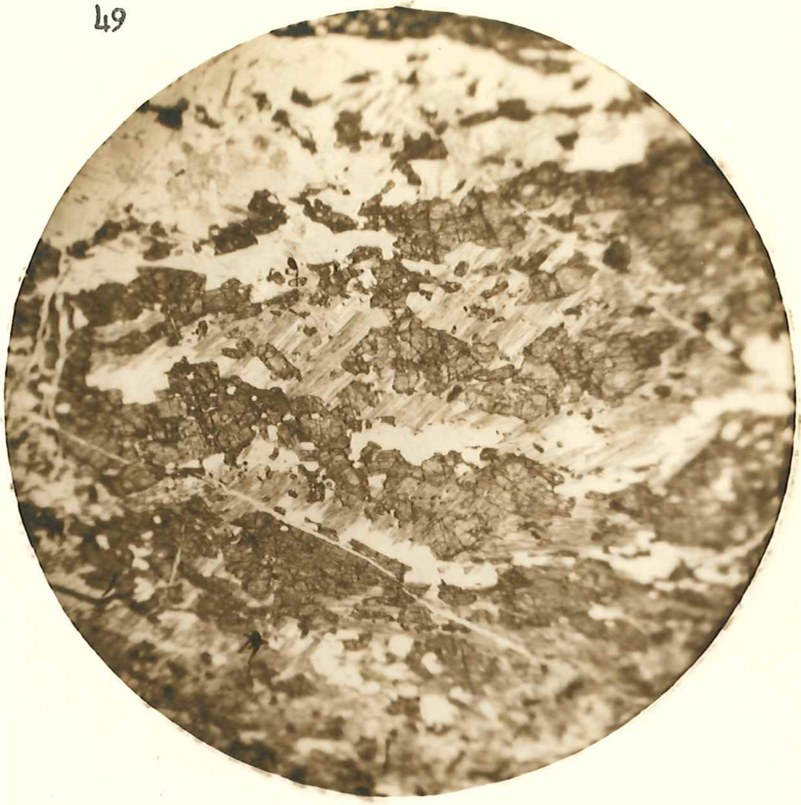


Plate 13. Banded epidote amphibolite, showing bands of epidote and sphene with later aggregates of acicular actinolite trending at an angle to them.
16X, plane light

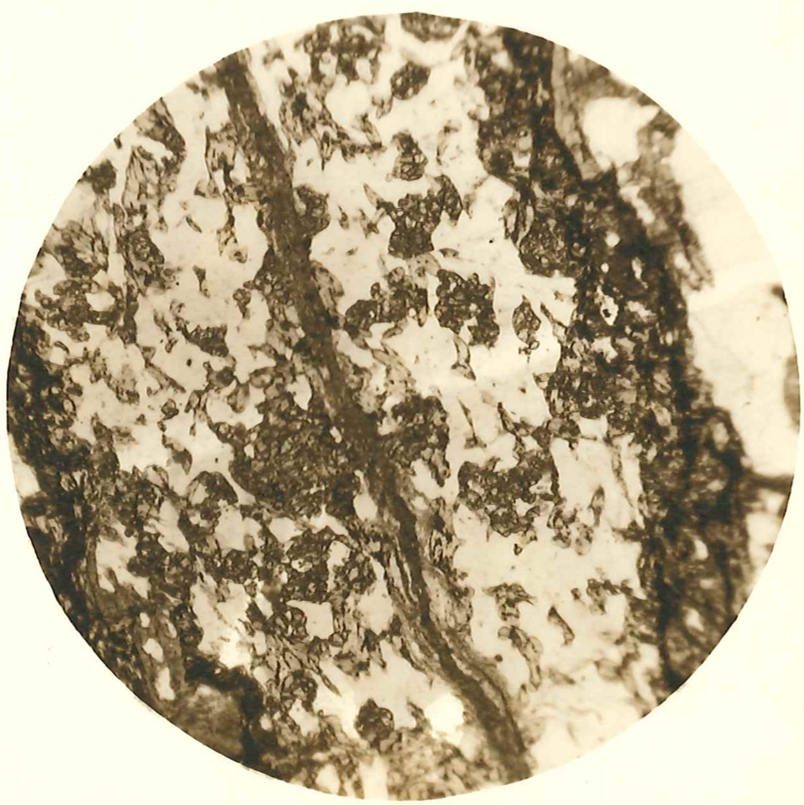


Plate 14. Banded epidote amphibolite, showing grains of garnet (dark) and retrogressive chlorite in quartzose band.
32X, plane light

of fine granular carbonate. The quartzites are similar, except for lack of carbonate.

TONALITE - DACITE PORPHYRY GROUP

These rocks may be treated as a unit because they form a gradational series texturally, and are similar in composition. Although they include both plutonic dike rock facies and presumably likewise intrusive volcanic facies, it would be arbitrary to divide these rocks into two separate groups. Megascopically, they all look similar and their outcrops have the same appearance. While their outcrops do not form conspicuous topographic features, they can be easily distinguished from the surrounding greenstones by their rectangular blocky pattern of weathering.

Occurrence and General Relationships

These rocks occur in widely scattered, usually very small outcrops. They tend to be more concentrated in a belt-like area, which trends southeast from a point just south of Strawberry Lake, where a major fault associated with a brecciated zone separates a larger outcrop of these rocks from greenstone (Plate 15). Wherever contacts were observed in the field, they appeared sharp, although rarely could they be traced for more than a few feet. Field evidence is not helpful in clarifying the primary geometric relationship between the intrusives and the older greenstones. In some areas these two rock types are so closely intermingled as to suggest a sort of large scale breccia. However, the weak metamorphism of the greenstones is older than the intrusion of the acidic igneous rocks. In some places, the intrusive rock seems to have suffered more hydrothermal alteration next to the contact than the greenstone, which might be misinterpreted as evidence for a higher age of the leucocratic rock. This apparent paradox is explained

1 inch

Plate 15. Breccia from contact zone south of Strawberry Lake composed of fragments of dacite porphyry, banded recrystallized chert, and actinolitic greenstone, tightly bound in a matrix of hornblendic material, albite, and reconstituted quartz.

by subsequent hydrothermal solutions moving more easily along a contact where it has been sheared or faulted.

The leucocratic intrusives have no visible surface expression that could be used to interpret their form. Presumably they are diaschistic apophyses derived from some larger subjacent mass.

Petrography

Petrographically, these rocks range from equigranular phanerites at one end of the series to porphyries with an aphanitic groundmass at the other. The predominant texture in the first instance is hypidiomorphic-granular, although in some, the grains are distinctly xenomorphic, forming a sugary texture, while in some others a tendency toward mortar structure exists.

The phaneritic members consist of 50-60% plagioclase, 30-40% quartz, with 10-20% hornblende and/or biotite. The plagioclase forms euhedral to subhedral plates, averaging about 1.5 mm. in length, with a maximum of 2 mm. Many show pronounced zoning, and some are poikilitic. The composition varies somewhat. The most reliable data indicate a range between $Ab_{65}An_{35}$ and $Ab_{55}An_{45}$, or middle to calcic andesine. The task of identification in thin section is complicated by apparent partial decalcification, which, in some cases, has resulted in the formation of more albitic rims. Peripheral albitic zones might, however, be original, due to fractional crystallization. Many phenocrysts exhibit pronounced zoning, which generally appears to be normal. In at least one instance, it is oscillatory.

Orthoclase was identified in one sample of tonalite. It constituted only about 5% of the volume, and occurred as irregular interstitial

Fig. 4. Mineral composition of samples from the acidic to intermediate intrusive volcanics computed from data obtained by modified Rosiwal analysis.

	Quartz %	Orthoclase %	Plagioclase %	Hornblende* %	Biotite* %	Groundmass %
Rhyolite Porphyry	8.0	12.0	6.5		3.2	70.2
Rhyolite P.	6.3	8.2	4.8			80.6
Dacite P.	18.5		39.7	3.4	4.0	34.2
Dacite P.	10.8		35.1	4.0	2.6	47.4
Dacite P.	13.3		31.3		9.9	45.6
Tonalite	28.0	4.8	53.2	10.7	3.3	
Andesite P.			7.1	26.4		66.4
Andesite P.	2.8		10.6	20.0		66.6
Diorite	9.2		57.7	33.1		

* Or pseudomorphic equivalent.

poikilitic masses, indicating a late stage of crystallization. The quartz occurs generally as anhedral grains, averaging about 0.5 mm. in size. Occasionally it forms somewhat poikilitic irregular masses, up to 3 mm. across. Where the hornblende is fresh, it occurs in euhedral prisms, which sometimes reach a length of 2 mm., but are generally shorter. Most of the hornblendes are partially altered to epidote and chlorite. Biotite is less frequent and its plates are smaller, the maximum size being about 1 mm. As a minor accessory, apatite occurs in tiny subhedral prisms, which often form inclusions within the plagioclase or quartz.

At the other end of the series are the pronouncedly porphyritic types. They are characterized by phenocrysts of plagioclase and quartz with or without minor hornblende and/or biotite phenocrysts, in a crypto-crystalline, felsic groundmass. The ratio of phenocrysts to groundmass reaches a minimum of around 30% in the most typically porphyritic varieties. As the ratio of phenocrysts increases, the rocks gradually pass into the more fully granular types described above. The grain size of the ground-mass varies from cryptocrystalline up to a sugary, fine-grained texture, in which the individual grains can be readily identified under the microscope. No trace of glass was found in the matrix. Flow structure in finely div-ided mafic material was observed in one instance. As the ratio of pheno-crysts increases, the matrix generally becomes less fine-grained.

The phenocrysts, in general, are euhedral to subhedral, although the quartz individuals show striking differences, both from one sample to another and in the same rock. Some are large (up to 4 mm.), usually equidimensional, with straight sharp faces, while others are rounded with deep resorption embayments (Plate 17). Some are extremely poikilitic

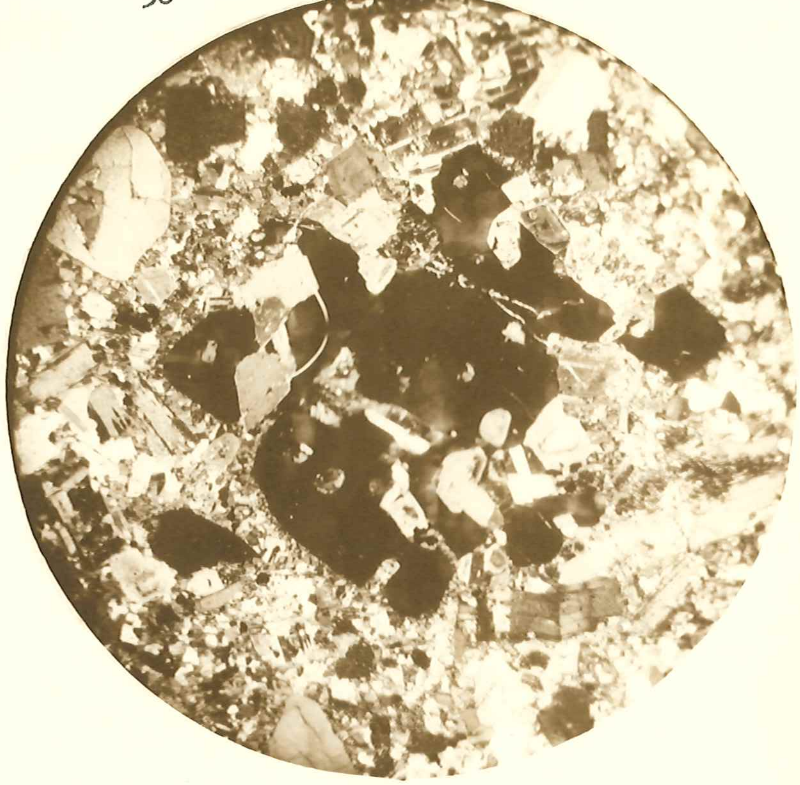


Plate 16. Quartz phenocryst (dark), deeply embayed and extremely poikilitic, in a dacite porphyry.
16X, crossed nicols

Plate 17. Quartz phenocryst (dark), showing deep resorption embayments, in a dacite porphyry. 32X, crossed nicols

(Plate 16), with inclusions of groundmass, as well as discrete grains of quartz, feldspar and mafics, and also often surrounded by auras of fine, angular, almost cataclastic-looking quartzo-feldspathic material, a sort of corona effect (Plate 19). Still others, usually smaller, are completely anhedral and often jagged, as if brecciated. These phenocrysts frequently occur in clusters, the individuals having different orientations. They constitute from 10-20% of the volume of the rock.

The feldspar phenocrysts are plagioclase. No potash feldspar was identified. The phenocrysts, where fresh, are euhedral to subhedral, somewhat poikilitic, and range up to 3 mm. in length. They comprise anywhere from 10% up to 50% of the rock. In composition, they are similar to the plagioclase of the phaneritic members, i.e., middle to calcic andesine. The hornblende and biotite phenocrysts display the same characteristics as the grains of these minerals which occur in the phanerites.

Although representing up to 50% of the rock in some cases, little can be said as to the nature of the groundmass, except that it is holocrystalline and predominantly felsic. No twinning lamellae were visible, but from the high differential relief among the grains, a large proportion of either albite or potash feldspar, or both, seems likely. This deduction is borne out by the presence of much plagioclase among the smaller grains in those members in which the groundmass becomes less dense, and by the presence of interstitial orthoclase in one of the phaneritic samples mentioned above. Also, a sample in which the phenocrysts are severely sericitized displays a highly sericitic groundmass as well, suggesting that in this one case at least, the groundmass was largely feldspathic.

Alteration

Part of these rocks are altered, some of them severely. Some of this alteration is presumably deuteric, while much of it is no doubt due to late hydrothermal action. The results of these two phases are sometimes difficult to distinguish, but, generally speaking, biotitization of the hornblendes is attributed to the deuteric phase, while those cases in which the hornblende is decomposed into chlorite and epidote or carbonate are assumed to belong to the later hydrothermal phase. After this decomposition, frequently all that remains are ragged prismatic pseudomorphs, largely composed of chlorite, with the released iron fixed as segregations of magnetite dust. The biotite plates are, in general, at least partially chloritized. The chlorite is pennine.

Alteration of the feldspars takes the form of sericitization, carbonatization, or saussuritization. Sericitization is the most prevalent, and is in fact almost ubiquitous, very few of these rocks having escaped at least partial attack. In many cases, sericitization of the plagioclase phenocrysts is complete.

Accessory minerals not mentioned above and probably associated with some phase of alteration include: pyrite in euhedral cubes and scattered irregular masses, itself often largely altered to limonite; and sphene as euhedra and irregular grains. Some of these minerals, especially pyrite, as well as late quartz, carbonate, epidote, chlorite, etc., are found in veinlets occupying fractures resulting from brecciation that marks a final stage in the history of these rocks.

DIORITE - ANDESITE PORPHYRY GROUP

These rocks constitute a series analogous to the one formed by the tonalite - dacite porphyry group, but appear to be much less widespread. Their outcrops are scattered, small in area, and in appearance similar to those of the tonalite and dacite.

The dioritic varieties contain 50-60% plagioclase, 30-40% hornblende, and 5-10% interstitial quartz. In one of these, a distinct and striking parallelism of the mineral constituents was noted. This involved both the plagioclase laths and the hornblende prisms (Plate 20). The plagioclase laths, mostly euhedral to subhedral, have suffered more alteration than in the more felsic varieties, with the result that their composition could not be ascertained. Peripheral zones, however, were determined to be albitic. Saussuritized plagioclase laths often display in their central parts a "dirty" aggregate of finely divided clinozoisite, carbonate and sericite (Plate 21). These are the same phenocrysts that show clear albitic rims. The saussuritization of the originally more calcic cores is presumably due to late hydrothermal action. The size of the plagioclase grains does not differ much from those in the tonalite.

The hornblende forms long euhedral prisms (maximum 3 mm.), generally strongly pleochroic, with Z = dark green, Y = olive green, X = yellow brown, although some more weakly pleochroic bluish green, presumably secondary, hornblende was observed. Frequently, these hornblendes are completely broken down into pseudomorphs of actinolite, chlorite, and calcite, probably as a result of low temperature deuteric action. In some cases, the

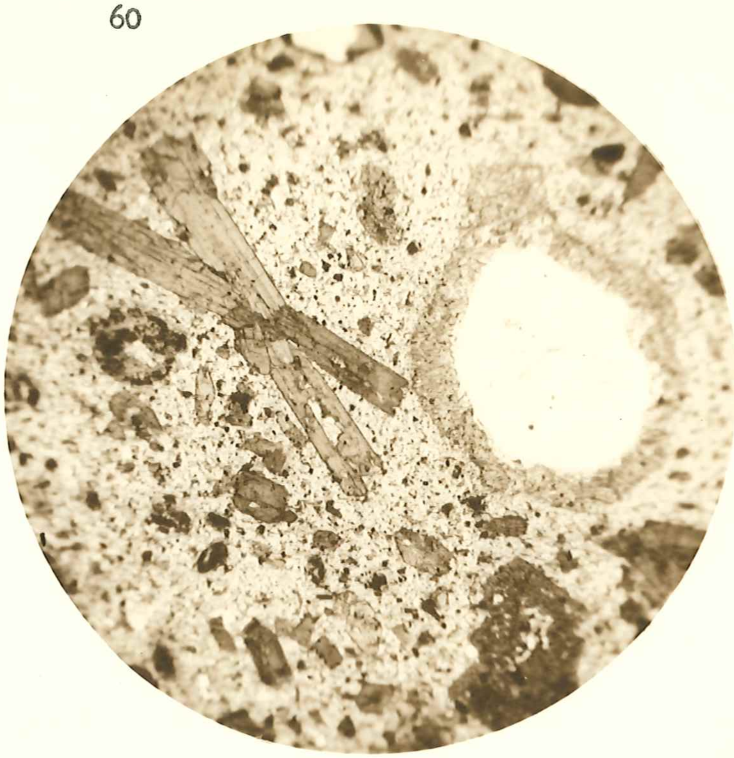


Plate 18. Hornblende-andesite porphyry, showing hornblende phenocryst (crossed prisms) and quartz phenocryst surrounded by reaction rim of chlorite and carbonate.

16X, plane light

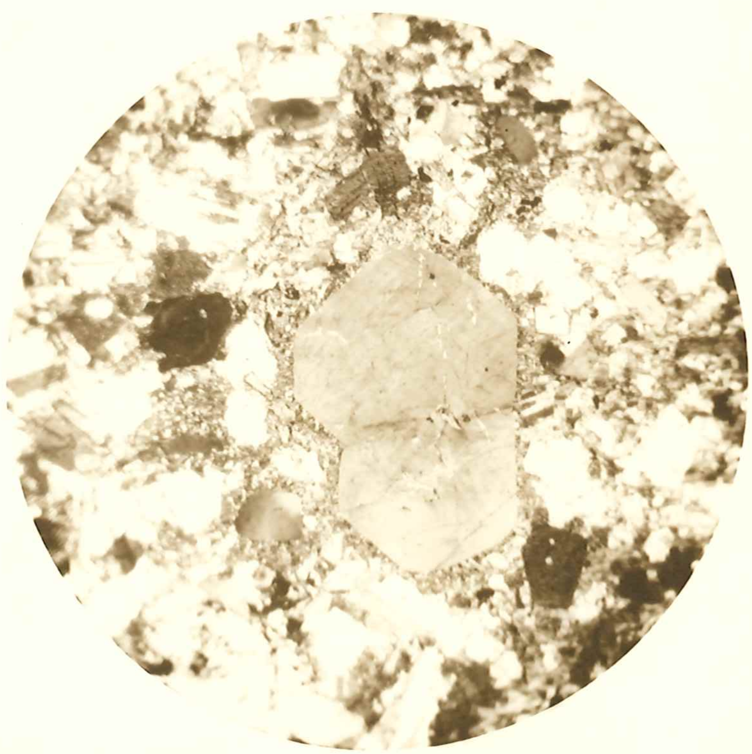


Plate 19. Euhedral Quartz Phenocryst in Dacite Porphyry.

16X, crossed nicols

pseudomorphs consist of aggregates of small, randomly oriented biotite plates, with the released calcium going into the formation of epidote and carbonate. This alteration was at a somewhat higher temperature, and can definitely be assigned to the deuteric phase. Quartz is very subordinate, being found as interstitial grains.

The porphyritic members are characterized by the presence of abundant hornblende phenocrysts with subordinate plagioclase phenocrysts in an aphanitic groundmass. The phenocrysts reach a minimum of about 30% of the rock in a typically andesitic end member. The hornblendes occur as slender prisms, up to 5 mm. long (Plate 18), but generally considerably smaller. When fresh, they are quite euhedral and strongly pleochroic. Most often, they are rather severely altered, which has weakened the pleochroism and resulted in more ragged surfaces.

The plagioclase phenocrysts are, for the most part, much smaller than the hornblendes, averaging 1 mm. in length, occasionally reaching a maximum size of 3 mm. Generally, they are heavily sericitized, if not completely decomposed, but a few plates yielded sufficient data to indicate a composition of $Ab_{55}An_{45}$. This is essentially the same as the plagioclase of the dacite porphyries.

Quartz is present in the andesite porphyries as occasional strongly resorbed phenocrysts (Plate 18), and as small scattered anhedral grains, grading down into the groundmass. An interesting feature in regard to the corrosion effects is that in these andesite porphyries, the peculiar aureoles surrounding the quartz phenocrysts are composed of carbonate and chlorite (presumably decomposition products of hornblende), instead of the

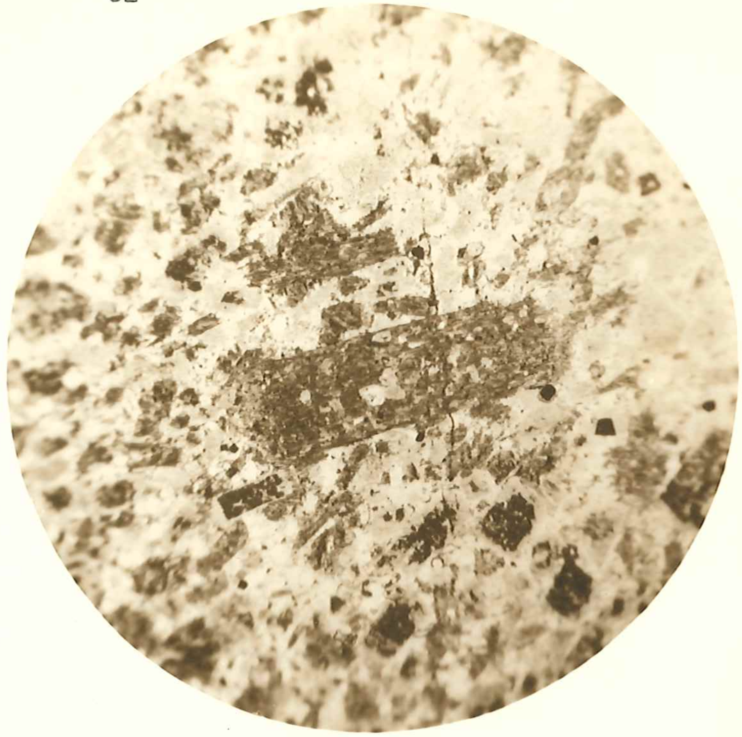


Plate 20. Andesite porphyry, showing crude flow structure, and hornblende phenocryst altered to biotite and carbonate.

16X, plane light

Plate 21. Diorite, showing strongly saussuritized plagioclase laths.

32X, plane light

quartzo-feldspathic material which forms these aureoles in the dacite porphyries.

The groundmass is fine-grained. In the typically andesite-porphyritic end members, the grain size reaches a minimum of .06-.07 mm. It appears to average about 20% hornblende with a considerable quantity of carbonate. Most of the rest is feldspar, but its exact composition could not be determined.

RHYOLITE PORPHYRY

General Considerations

This rock differs from the dacite porphyries in several important respects, while resembling them somewhat in texture and general appearance. Its outcrops are fewer in number, although just as widely distributed and covering the same general area. Contact relationships with the greenstones are apparently much the same, and, unfortunately, no contacts with the other porphyries were observed. One possibly significant difference lies in the fact that, unlike the dacites, these rocks are not involved in any jumbled breccias with the greenstones. Also, they are remarkably uniform in being poor in mafic minerals, in having a dense groundmass, and in the size of their phenocrysts and their ratio to the groundmass.

Petrography

As stated above, the groundmass predominates over the phenocrysts to a much greater extent than in the dacite porphyries, ranging from 65 to 80%. Although not vitric, it is extremely dense, the average grain size being around .04 mm. It is almost completely felsic, although the quartz-feldspar ratio, as well as the kinds of feldspar present, could not be determined. No flow structures were observed.

The phenocrysts are quartz, orthoclase and plagioclase, and, in one section, very minor green biotite pseudomorphs after hornblende. The phenocrysts are generally smaller than in the dacite porphyries, but just as euhedral. An unusual feature is the occurrence of clusters of phenocrysts, made up of individually euhedral grains of quartz and orthoclase or plagioclase (Plate 22). This rock may be named a glomeroporphyry. Many phenocrysts consist of intergrowths of somewhat rounded rods of quartz with both orthoclase and plagioclase (Plate 23).

The quartz phenocrysts are rather more euhedral than in the dacites. They show some corrosion, but not as marked as in the other porphyries. They are, for the most part, equidimensional, and average about 0.8 mm. in diameter. They are more numerous than the orthoclase, but, due to their smaller size, they comprise only a little more than half as much volume as the orthoclase.

Orthoclase occurs as generally thick, more or less equant, mostly euhedral plates, frequently in composite aggregates, and often in granophyric intergrowth with quartz. Some contain inclusions of plagioclase in addition to quartz. The phenocrysts average about 2 mm. in length. Some show partial resorption.

The plagioclase phenocrysts are considerably smaller (average about 1 mm.), and constitute correspondingly less of the volume (6%) of the rock. The few that are not completely sericitized were found to be $Ab_{95}An_5$, or nearly pure albite. They, too, frequently show granophyric intergrowth with quartz.

Alteration

The feldspars in these rocks have been strongly but selectively altered, presumably both deuterically and later hydrothermally. The plagioclase has, almost without exception, been severely sericitized, with subordinate carbonatization, while orthoclase phenocrysts are lightly

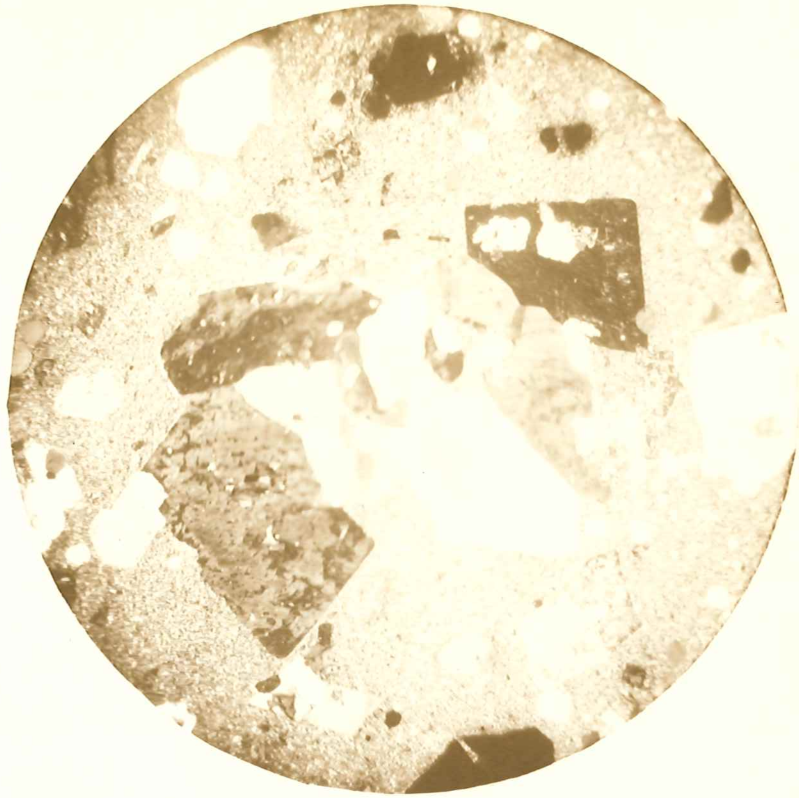


Plate 22. Rhyolite porphyry, showing phenocryst cluster, composed of orthoclase and quartz.
16X, crossed nicols

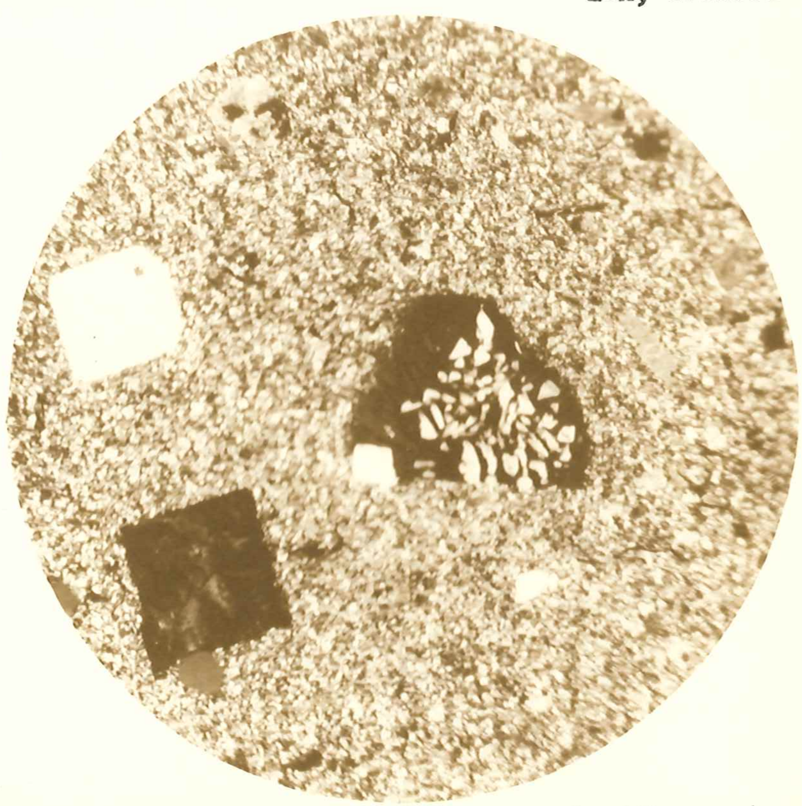


Plate 23. Rhyolite porphyry, showing orthoclase phenocryst with quartz intergrowth and euhedral quartz phenocrysts. 32X, crossed nicols

kaolinized with considerable partial replacement by calcite. The presence of so much secondary calcite seems very surprising in view of the highly alkaline nature of the feldspars and the lack of mafic minerals. Most of the samples studied showed widespread sericitization of the groundmass, in addition to part of the plagioclase phenocrysts. In some samples, however, the groundmass is fresh and alteration restricted to the phenocrysts. In the case in which biotite was noted in pseudomorphs, presumably after hornblende, this alteration, at relatively still higher temperature, is presumed to be deuteric. Subsequent partial sericitization with fixation of released iron as dusty magnetite is attributed to later hydrothermal action.

The rhyolite porphyries, too, are strongly fractured, with indications that periods of sericitization both preceded and followed brecciation. The second period of sericitization coincided with the time of introduction of pyrite and other minor metallization. That these fractures existed for some time, and near the surface, is demonstrated by the presence of comb quartz along with pyrite in veinlets transecting the rock. Carbonate is the final vein filling. This may indicate that the carbonatization of the feldspars belongs to the same late phase of alteration. If this conclusion is correct, then it may help to date the sericitization of the feldspars, which, in some cases at least, appears to be contemporaneous with their carbonatization.

FELDSPATHIZED ROCKS OF SEDIMENTARY AND IGNEOUS ORIGIN

In a few small, but rather well-defined, areas of inconspicuous outcrops, occur leucocratic rocks which are massive, fine-grained and generally rather severely brecciated. Megascopically, few identifying features can be recognized. In one area, these rocks are rather closely associated with quartzitic metasediments; in another, they outcrop with amphibolites and greenstones. Thus, there seems to be no field relationship to aid in determination of the nature of these rocks.

Petrography

In thin section, the outstanding characteristics of these rocks are readily apparent: (1) their textures are distinctly crystalloblastic and porphyroblastic; (2) albite and quartz are the predominant minerals.

Some of these rocks are obviously of sedimentary origin. In these, many of the large quartz porphyroblasts exhibit fine sieve structures, with inclusions of finely granular quartz, which evidently constituted a large part of the original groundmass. In one thin section containing albite porphyroblasts, relict folds in a sericitic groundmass can be seen. In one outcrop area, these albite-rich rocks can be traced into the quartzites, and thin sections show all gradations from rocks containing only a few tiny subhedral plagioclase grains with indistinct twinning lamellae, to rocks consisting of 50% or more albite, partly in the form of large, digital porphyroblasts, or cumuloblasts with quartz. The quartz frequently shows a pseudo-cataclastic texture. Its collective crystallization has produced large elongate masses which exhibit undulatory extinction. For the most part, the albite grains are fresh and clear, especially the smaller ones; occasionally, they are slightly sericitized. Minor constituents in these rocks are: carbonate, chlorite, biotite (or stilpnomelane), sericite, and, infrequently, a little epidote. The carbonate is apparently in equilibrium with the plagioclase, and is present in scattered irregular masses, as well as in veinlets. Very infrequently, a grain or two of microcline can be seen.

The mineral assemblage is typically epizonal, indicating low temperature hydrothermal action as the agent of metamorphism. There are several reasons for believing that these rocks may be the youngest in the area. First, most of their feldspars are entirely fresh and clear. The quartz, which in some cases partially replaces the feldspar, is at least as late as, and in part even later than, the albite. Second, and perhaps more important, is the tectonic evidence. In contrast to most of the minerals in the isochemically metamorphosed rocks, most of the subhedral albite plates are only slightly deformed. Only in some cases are the twinning lamellae bent or twisted, sometimes fractured, and subsequently healed. Some plagioclase plates have grown into fractures and stopped there, instead of being ruptured by them. It is therefore clear that albite growth has outlasted all but the very latest phase of fracturing. In some samples, however, the presence of cataclastic quartz in the form of porphyroclasts, indicates that the quartz has in part also been affected by this latest brecciation.

The question arises as to the source of the albite, especially of its sodium, in the albitized metasediments. Was the albite crystallized from elements already present in the sediment, or was its sodium introduced in solution? There is strong evidence for the latter hypothesis. The normal argillites of the area (cf. above) do not contain enough sodium to account for so much albite, as is shown by their mineral compositions. In fact, the sodium content of argillaceous sediments is generally lower than their potassium content. The more highly quartzose metasediments of the area would be even poorer in original sodium. This general chemical argument is supported by the sieve and porphyroblastic textures commonly shown by the albite crystals, and indicating a replacement origin for these crystals.

So far, only those samples which are plainly of sedimentary derivation have been considered. There are also albitic rocks that are equally plainly derived from dioritic rocks. In addition, there are other types of more doubtful origin. In the altered dioritic rocks, the original feldspars generally are subhedral, turbid and sericitized, and often bent or twisted. The composition of these feldspars remains doubtful, owing to their advanced decomposition. In addition, there is a second feldspar, consisting of smaller clear xenoblastic albite grains, identified as $Ab_{95}An_5$ (Plate 28). Many of the usually platy albite xenoblasts exhibit bent and ruptured twin lamellae, which have been subsequently healed (Plate 25). Thus albitization has occurred at the time of tectonic fracturing.

Together with albitization, replacement of plagioclase by quartz is the dominant characteristic of these rocks of dioritic derivation. This latter feature is exemplified in the large digital or amoeboid masses of quartz which can be observed replacing the earlier feldspar, as well as the late albite (Plate 27). Frequently, epidote, a by-product of the

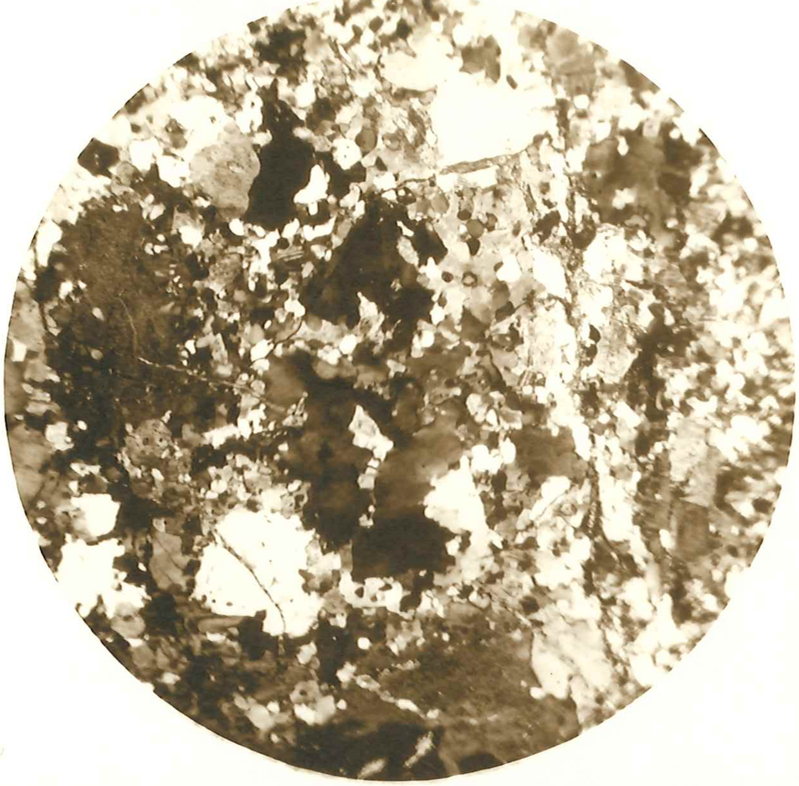


Plate 24. Quartz replacing calcic plagioclase with concomitant formation of albite and epidote -- in rock of doubtful origin.
32X, crossed nicols

Plate 25. Albite porphyroblast in feldspathized sediment; crystal has been fractured and the two segments slightly displaced by subsequent movement.
32X, crossed nicols

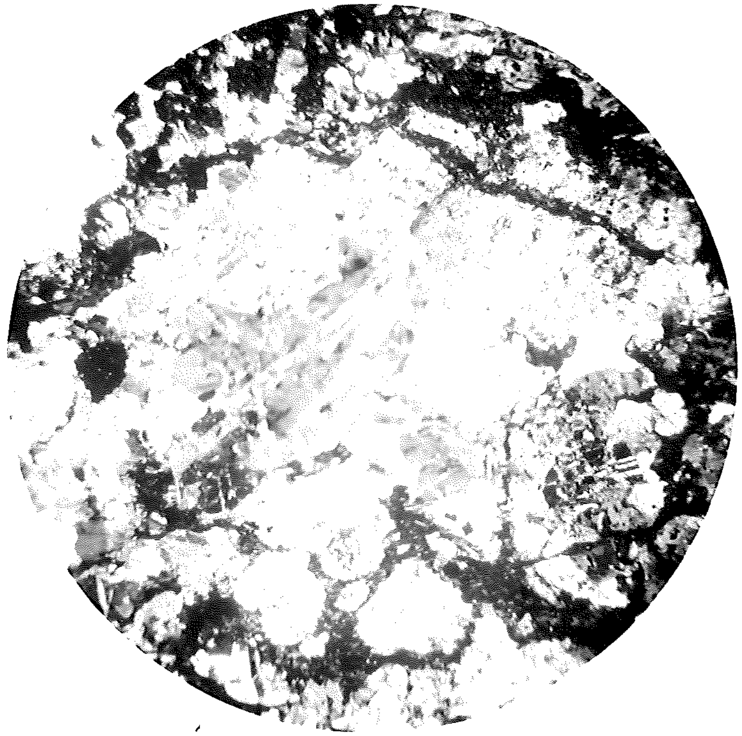


Plate 26. Replacement texture in albitized rock of doubtful origin.
16X, crossed nicols

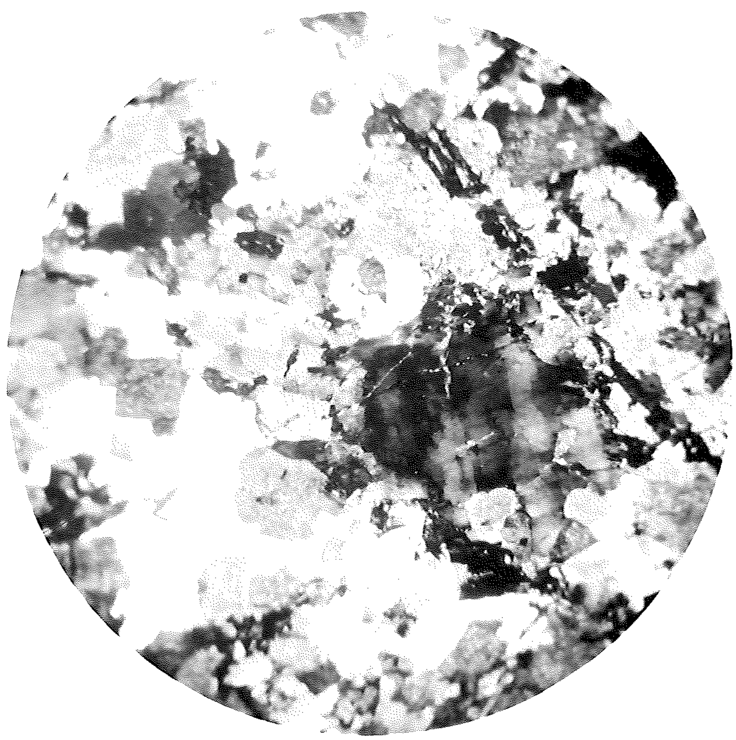


Plate 27. Metasomatic quartz (dark) in feldspathized rock of doubtful origin.
16X, crossed nicols

Plate 28. Replacement texture in feldspathized rock, showing metasomatic albite and quartz.

16X, crossed nicols

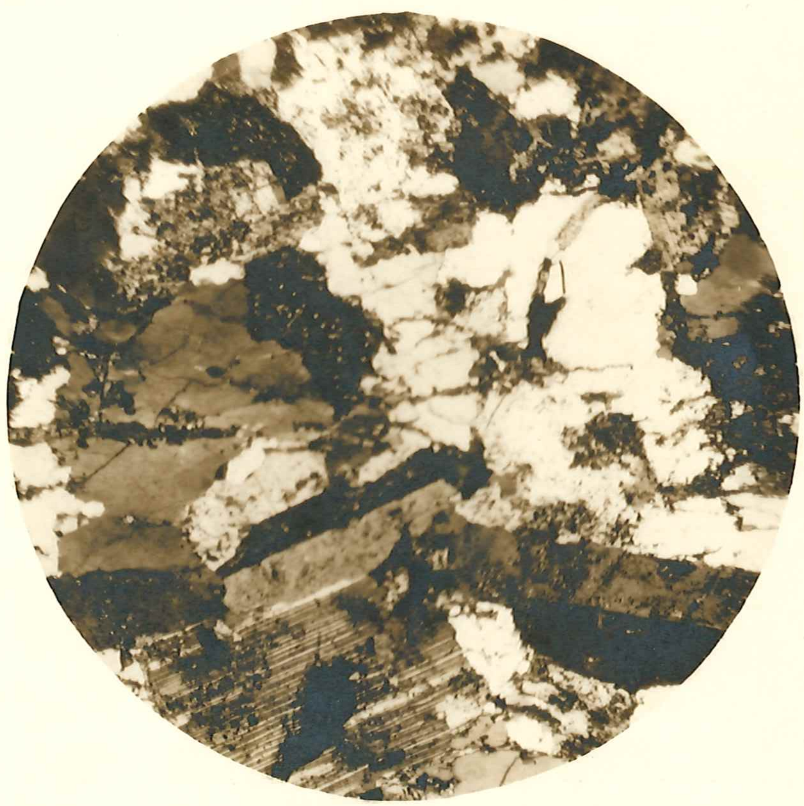


Plate 29. Quartz and albite porphyroblasts in feldspathized rock of undetermined origin. 32X, crossed nicols

albitization, remains as inclusions in the quartz (Plate 24). Sometimes relict twinning lamellae can be detected in the marginal areas of the advancing quartz. There are also relict veinlets of fine-grained quartz faintly visible in some of the larger quartz masses.

There can be little doubt that these rocks are albitized and silicified members of the tonalite-dacite or diorite-andesite series, as described above. Many of the albitized rocks which were observed occur at or near contacts of these intrusives with the country rock. In some cases, the country rock is an amphibolite; in one case, it is a biotite hornfels. Whether the occurrence of albitized rocks at such contacts is genetically significant, or whether it merely represents chance observations, is problematical. However, in each case where the albitized and silicified diorites were found to occur in contact with the country rock, the latter was seen to be of a higher metamorphic grade than the normal dense greenstone. This fact suggests that where temperatures were high enough to form mesozonal assemblages in the country rocks, hydrothermal metasomatizing solutions were more active. In addition, the contacts themselves being discontinuities, may have provided a means of access for the solutions.

On first inspection, these country rocks in contact with the altered intrusives appear to be fresher than the intrusives, which frequently contain altered mafic minerals (epidote and carbonate pseudomorphs after hornblende, as well as chloritized biotite). This naturally raises the question as to why, if these acidic intrusives are younger, as they are presumed to be, they should be characterized by alteration and replacement, while the country rocks with which they are in contact seem unaffected. The twofold answer to this is: (1) the acidic intrusives are not, in all cases, altered -- indeed, many of them are extremely fresh; and (2) the country rocks are not completely unaffected; although they have not apparently been silicified, many of the amphibolite samples show some retrograde sericitization, as well as scattered chlorite and carbonate. In addition, albite is one of the major constituents of the amphibolite, and, although the albite grains appear to form a mosaic with the hornblende, indicating simultaneous crystallization, there is also the possibility that the sericitization mentioned above is due to differential alteration of partially decalcified plagioclase. In other words, these amphibolites could have been albitized, perhaps even contemporaneously with the acidic intrusives, and by the same metasomatizing solutions. Also, some of the samples of breccia, composed of fragments of low grade amphibolite and acidic intrusive, have a matrix consisting of porphyroblastic quartz and alkali feldspar, indicating silicification as well as feldspathization, in proximity to contacts not unlike those described above.

This albitization and silicification, then, could represent endomorphic effects of the intrusion of the acidic volcanics, insofar as they affect these latter rocks, and exomorphic effects in the altered country rocks, including the amphibolites and the albitized metasediments.

Among the alkali feldspar-rich rocks of more doubtful origin (cf. above) is one that deserves special mention, for one reason, at least. It is the only rock encountered that contains a considerable proportion of microcline. This occurs as anhedral grains, very slightly kaolinized, lying among heavily sericitized subhedral grains of plagioclase and smaller anhedral quartz grains. A few scattered flakes of chlorite represent the only mafic mineral. The composition of the plagioclase could not be precisely determined, but it is probably albite. The texture is not typically metasomatic, and thus perhaps the rock should not be discussed here, but because of the unusual occurrence of microcline, it seemed best to include it.

METAMORPHIC ZONING AND HISTORY

The mineral assemblages in both greenstones and metasediments indicate that, in general, most of the rocks of the area belong to the greenschist facies, equivalent to the low grade zone or epizone of regional metamorphism, although some rocks represent a somewhat higher grade.

In contrast to more typical areas of epizonal regional metamorphism, most of the rocks in this area are not very pronouncedly schistose, and many of them even lack schistosity altogether. In the absence of strong and uniform penetrative deformation, the metamorphism must be largely attributed to low temperature hydrothermal action on a regional scale. We may speak of regional hydrothermal metamorphism. In those rocks which have undergone a higher degree of penetrative deformation than the rest, and which thus have become more typically schistose, metamorphic recrystallization is frequently more pronounced. It is thus indicated that locally stronger penetrative deformation has been an additional factor in promoting metamorphism.

Low grade mineral assemblages indicate that low temperatures generally prevailed, while extensive and intensive brecciation demonstrate that the deformation took place at a relatively shallow depth. Intense hydrothermal action has been responsible for filling of the fractures, producing the extraordinary network of veining that is so characteristic of the area. It has also resulted in the chloritization, and the more local biotitization, the rather widespread sericitization, and the presence of infrequent crystalloblastic alkali feldspar. The ubiquitous occurrence of pyrite, irrespective of rock type or age, is further indication of the prevalence of hydrothermal solutions.

In the cases in which a somewhat higher grade of metamorphism has been attained, however, there seems to be no schistosity, with the exception of the group of banded epidote amphibolites which occur in the northeast part of the area. Since, with the exception of these amphibolites, the higher grade rocks outcrop in proximity to the main belt of acidic intrusives, it seems highly probable that these higher grade rocks can be attributed to contact metamorphism, resulting from intrusion of the acidic rocks. Generally, these higher grade rocks have superimposed low grade mineral assemblages corresponding to the alteration found in many of the acidic intrusives. Thus it is concluded that alteration of the acidic intrusives, including albitization and silicification, and the retrogressive assemblages found in the neighboring higher grade rocks, belong to the same period of metamorphism, and that they represent endomorphic and exomorphic hydrothermal effects, respectively, of the intrusion itself.

If this hypothesis is correct, then the regionally occurring low grade facies represented in the greenstones and the metasediments, exclusive of their later local albitization, must be a result of an earlier period of hydrothermal metamorphism which preceded the emplacement of the acidic and intermediate intrusives. This is not an unwarranted conclusion, inasmuch as the local albitization in the metasediments was shown to represent the latest phase of metamorphism in these rocks. Also, the greenstones are too thoroughly transformed and too strongly sheared to have been produced by the same metamorphic action that caused the slight alteration, in part practically lacking, of the acidic intrusives. Some of the greenstones are even schistose, which fact further precludes any possibility of contemporaneity of these rocks with the massive, often fresh, and only slightly and locally brecciated acidic intrusives.

There is the probability that some of the rocks in the area may represent a period of metamorphism older than that which made the greenstones. Such polymetamorphism is, in particular, suggested by the banded epidote amphibolites in the northeast corner of the area. These rocks were first metamorphosed in the epidote-amphibolite facies under mesozonal conditions. Later on, a retrogressive epizonal metamorphism was superimposed. This second period of metamorphism corresponds to the epizonal alteration typical of the greenstones and associated metasediments.

The calc-silicate rocks represent the highest grade of metamorphism encountered in this area. They are subject to two possible alternative interpretations. Either they belong to an older metamorphic series, as the banded epidote-amphibolites do, or they are the products of a more recent contact metamorphism, resulting from intrusions which did not reach the surface in the immediate vicinity of these bodies. (Outcrops of the tonalite-dacite groups do occur, however, within a few hundred feet.) The fact that a superimposed retrogressive facies exists in the calc-silicate rocks would lend support to the former hypothesis, but the lower grade assemblage could have resulted from subsequent hydrothermal metamorphism, since the acidic and intermediate intrusives which would have to be held responsible for the contact effects, themselves show, in most instances, alteration corresponding to this retrogressive assemblage.

The ortho-amphibolites associated with the altered basic plutonics certainly represent a higher grade of metamorphism than the surrounding rocks. They could belong to an earlier rock group, but they are mostly fresh and do not show, to any considerable degree, the superimposed retrogressive facies characteristic of both the para-amphibolites and the calc-silicate rocks. Nor are they schistose. Thus, it is likely that they were formed by contact metamorphism of the greenstones, resulting from the higher temperatures induced by the acidic and intermediate intrusives (tonalite-dacites or diorite-andesites). This theory is supported by the areal distribution of these rocks (cf. the distribution of hornblende as shown in the map plate which illustrates the metamorphic mineral assemblages). However, amphibolites of probable igneous origin from the northern part of the area, discussed previously, show a retrogressive facies, as well as relict schistosity, indicating that, if they were derived from the greenstones as the other amphibolites presumably were, then they must first have passed through a period of deformation, followed by mesozonal porphyroblastic development of the hornblende, and finally, by retrogressive epidote and chlorite. It is, of course, possible that these amphibolites belong to an earlier group, perhaps contemporaneous with the banded epidote amphibolites, which outcrop a few hundred yards to the east, although the quartzites and other metasediments closely associated with the questionable amphibolites are, ostensibly at least, part of the main group of metasediments discussed above, which would seem to preclude an earlier age for the questionable amphibolites. Perhaps the possibility of selective metamorphism should also be considered. Another possible interpretation would be that these questionable amphibolites actually are part of an older metamorphic series, and were later on by tectonic slicing mixed with the sediments and suffered low grade hydrothermal metamorphism together with them. Certainly, these questionable amphibolites seem to have too complex a history to be correlated with the other amphibolites in the area, even if they were not dissimilar in texture, and somewhat in composition as well.

Thus, the oldest rocks in the area may be the banded epidote-amphibolite-quartzite complex in the northeast, possibly together with the northern amphibolites of doubtful origin, and, perhaps, but probably not, the calc-silicate rocks. Next oldest, presumably, are deposition and later on the epizonal metamorphism of the greenstones and associated metasediments, followed by the intrusive tonalite-dacite and diorite-andesite group, and, lastly, by the intrusive rhyolite porphyries. The last period of generally weak hydrothermal metamorphism was presumably a dying phase of this later intrusive-volcanic activity, accompanied by extensive weak brecciation and light sodium and potassium metasomatism.

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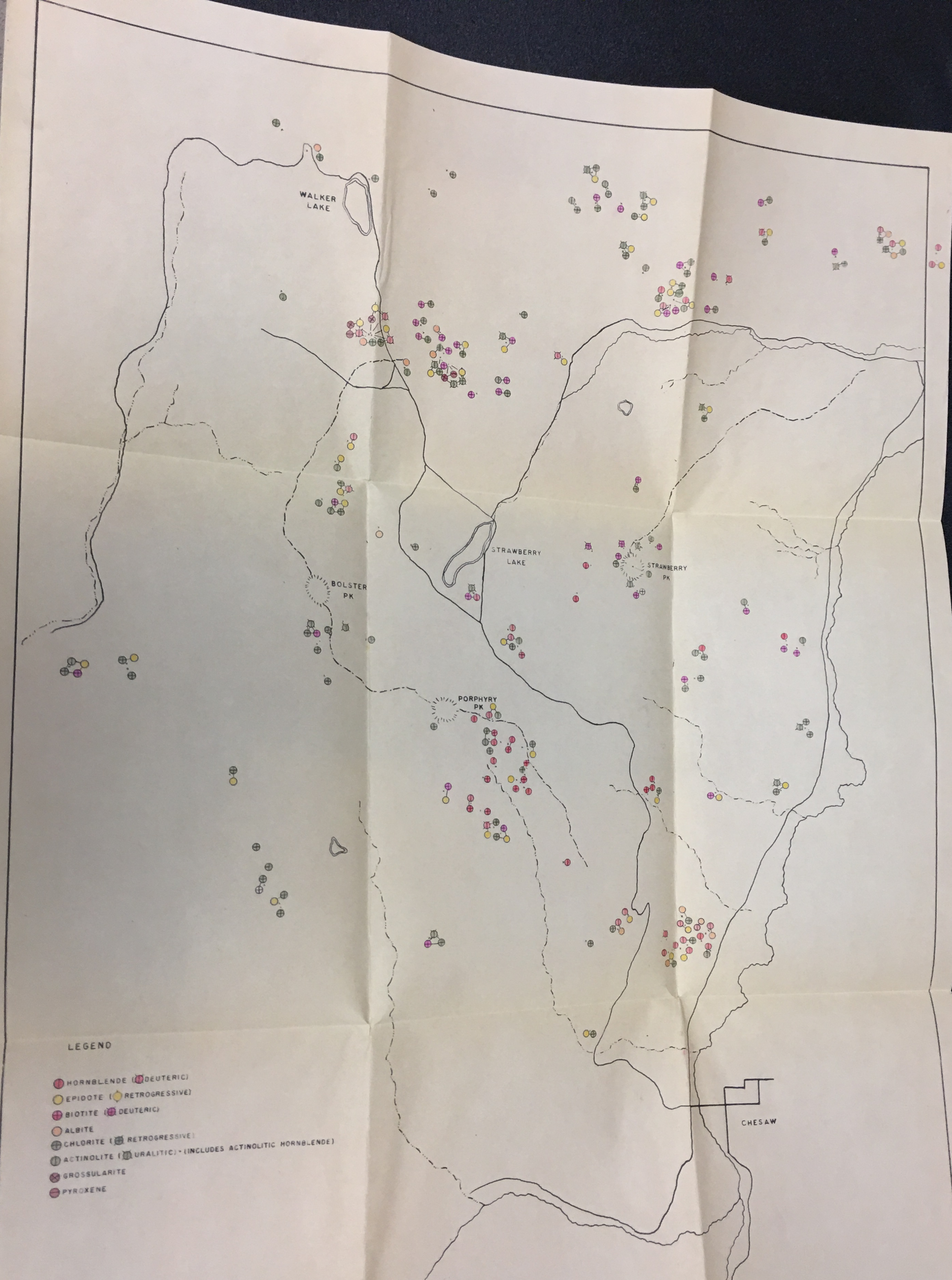
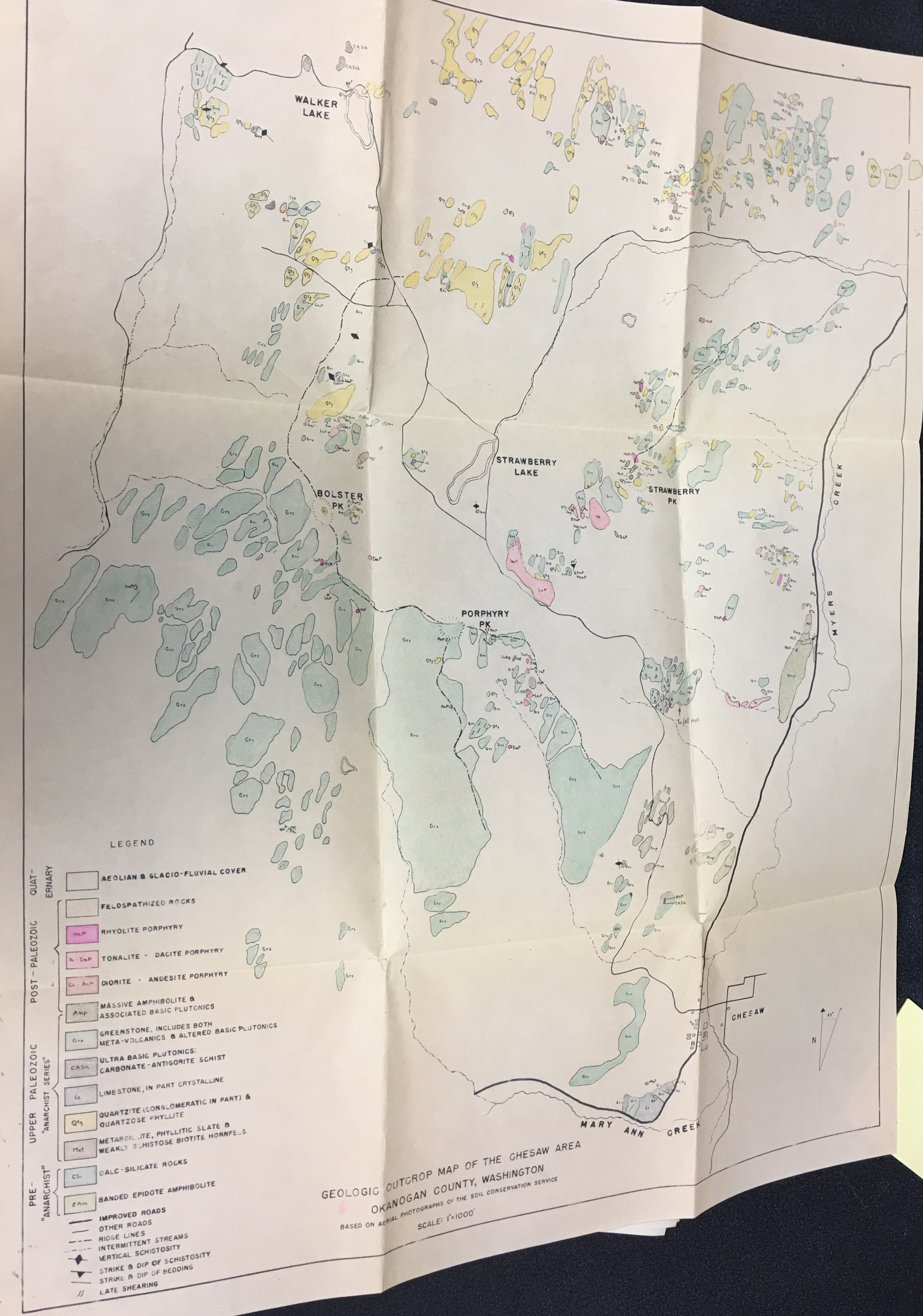


METAMORPHIC FACIES MAP OF THE CHESAW AREA
OKANOGAN COUNTY, WASHINGTON

SCALE: 1" = 1000'



GEOLOGIC OUTCROP MAP OF THE CHESAW AREA
OKANOGAN COUNTY, WASHINGTON
BASED ON AERIAL PHOTOGRAPHS OF THE SOIL CONSERVATION SERVICE
SCALE: 1"=1000'
WALKER LAKE
STRAWBERRY LAKE
STRAWBERRY PK
BOLSTER PK
PORPHYRY PK
MYERS CREEK
MARY ANN CREEK
CHESAW
N
LEGEND
QUATERNARY
AEOLIAN & GLACIO-FLUVIAL COVER
FELDSPATHIZED ROCKS
POST-PALEOZOIC
RHYOLITE PORPHYRY
TONALITE - DACITE PORPHYRY
DIORITE - ANDESITE PORPHYRY
UPPER PALEOZOIC "ANARCHIST SERIES"
MASSIVE AMPHIBOLITE & ASSOCIATED BASIC PLUTONICS
GREENSTONE, INCLUDES BOTH META-VOLCANICS & ALTERED BASIC PLUTONICS
ULTRA BASIC PLUTONICS: CARBONATE-ANTIGORITE SCHIST
LIMESTONE, IN PART CRYSTALLINE
QUARTZITE (CONGLOMERATIC IN PART) & QUARTZOSE PHYLLITE
METARGILLITE, PHYLLITIC SLATE & WEAKLY SCHISTOSE BIOTITE HORNFELS
PRE-"ANARCHIST"
CALC-SILICATE ROCKS
BANDED EPIDOTE AMPHIBOLITE
IMPROVED ROADS
OTHER ROADS
RIDGE LINES
INTERMITTENT STREAMS
VERTICAL SCHISTOSITY
STRIKE & DIP OF SCHISTOSITY
STRIKE & DIP OF BEDDING
LATE SHEARING